DATA CENTER ENERGY BENCHMARKING CASE STUDY

DECEMBER 2002

FACILITY 6

SPONSORED BY:

LAWRENCE BERKELEY NATIONAL LABORATORY

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I. Executive Summary

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's Data Center Load Characterization and Roadmap Project, under sponsorship by the California Energy Commission (CEC). This study is intended to provide measured information on energy and power use in data centers, and to help designers make better decisions about the design and construction of data centers in the near future. This report describes the outcomes of energy benchmarking in two data centers in Northern California, and the observations on potential opportunities in efficiency improvement. Data centers at different organizations in Northern California were analyzed, with the particular aim of determining the end-use of electricity.

This report documents the findings for one of the case studies – termed Data Center Facility 6. Additional case studies and benchmark results as they become available will be provided on LBNL's website (http://datacenters.lbl.gov) For comparison purposes, the results of a similar benchmarking study completed for the Pacific Gas and Electric Company (PG&E) in 2001 are included in this report.

Facility 6 contains two data centers, in two separate office buildings. These data centers contain mainly server type computers and data storage devices and resemble the server farms that became common as a result of the Internet Age.[1] Both Data Center 6.1 and Data Center 6.2 areas in facility A represent approximately 3% of the total building area. This percentage is a relatively small percentage, therefore the end use electricity of the whole building was not evaluated. Data Centers 6.1 and 6.2 were each 2,400, and 2,500 square feet (sf) respectively. Both data centers were primarily cooled by chilled water feeding computer room air handlers (Data Center 6.1), or fan coil units (Data Center 6.2). Both data centers were conditioned with overhead supply air and did not utilize raised floors.

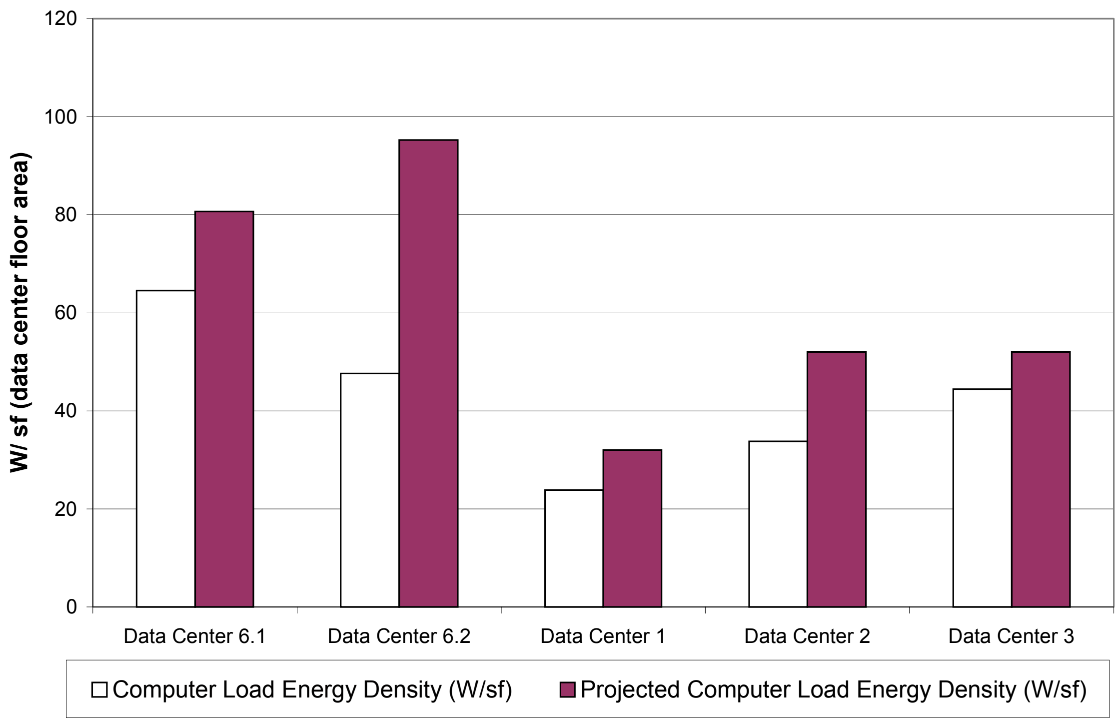
The current computer energy loads are listed in the table below. A qualitative estimate of the loading of the racks was made, and the future computer energy loads were estimated based on this loading. For comparison purposes the computer loads of the data centers studied in the PG&E project are also included (Data Centers 1, 2, and 3). The computer loads are also shown graphically.

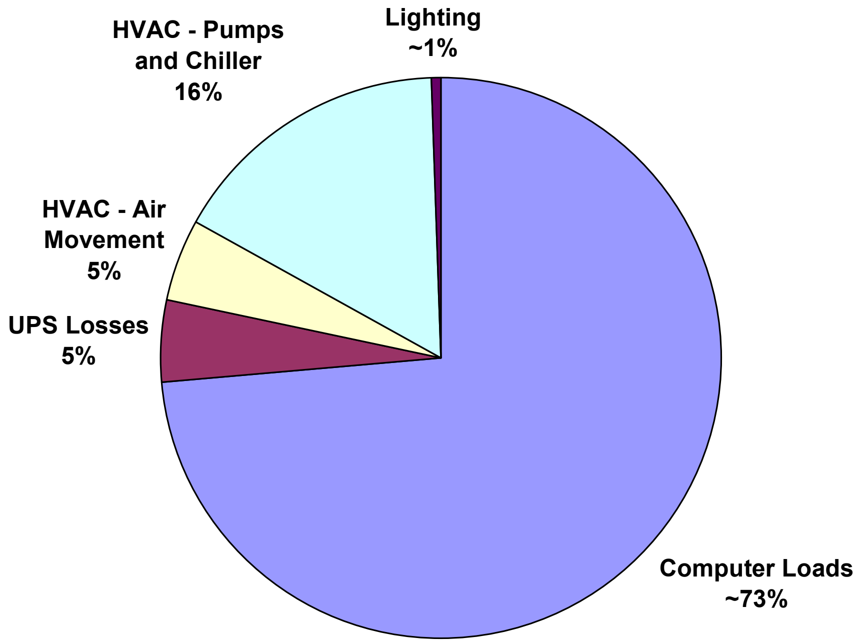
The measured computer load densities at Facility 6 are greater than the computer load densities measured in the previous PG&E study. The measurements project full occupancy densities of 81 and 95 W/sf, which are considerably higher than the full occupancy density projected in the PG&E study. The remaining energy loads of Data Centers 6.1 and 6.2 include air conditioning loads, lighting, and uninterruptible power supply inefficiencies. They are shown in graphical format below, as well as tabular format in the report.

[1] Based on the rack configuration, high density of computers, and absence of the large mainframe servers that were common in older data centers.

Current and Future Computer Loads

Data Center	Data Center Area (sf)	Computer Load (kW)	Computer Load Energy Density (W/sf)	Occupancy (%)	Projected Computer Load Energy Density (W/sf)	Number of Racks	kW/ Rack
6.1	2,400	155	65	80%	81	101	1.5
6.2	2,500	119	48	50%	95	83	1.4
1	62,870	1,500	24	75%	32	--	--
2	60,400	2,040	34	65%	52	--	--
3	25,000	1,110	44	85%	52	--	--





A large percentage, approximately 73%, of the total electrical load is from the computer loads. However, the HVAC loads totaled 21%. Since this represents a large percentage, efficiency improvements could result in significant energy savings. A number of energy efficiency metrics were calculated, including UPS efficiency, chiller efficiency, and air handler efficiency. A useful efficiency metric, particularly for data centers is a cooling efficiency, calculated as a ratio of cooling energy to computer load energy. These are shown below.

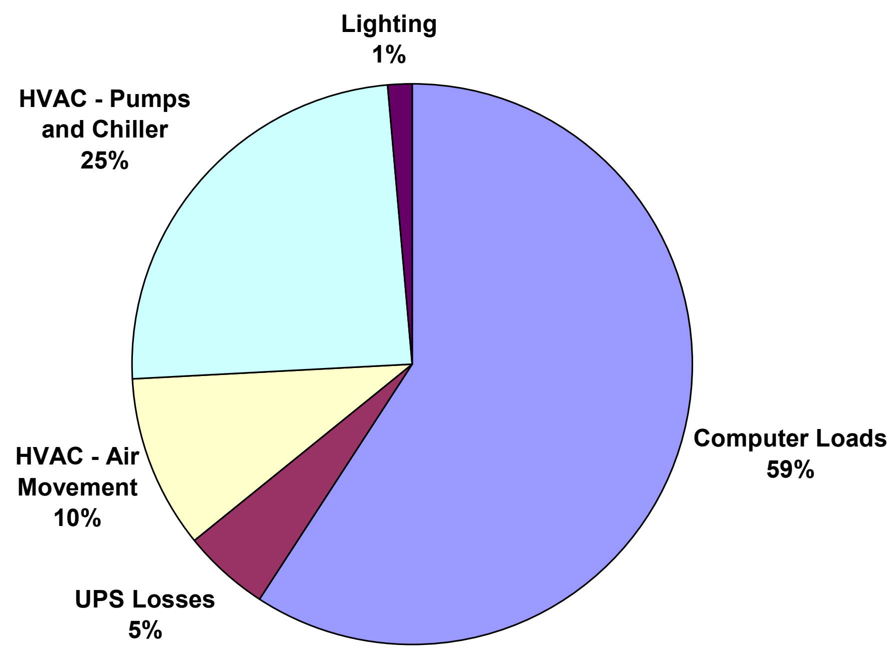
A more detailed discussion is presented in the report. In summary, the measured efficiencies of the chillers were approximately equal to their design efficiencies, as would be expected for the operating conditions. This is because the design efficiencies are based on 95 °F entering condenser temperature. When outdoor air temperatures are below this temperature, the chiller can reject energy more easily, and therefore has lower power consumption. Based on the outdoor air conditions in this geographical area, better efficiencies are expected. The air handler efficiencies were below their design efficiencies; this is likely due to excess pressure losses through the ducting.

DATA CENTER 6.1 EFFICIENCY METRICS

Efficiency Metric	Value	Units
UPS Efficiency	94%	--
Cooling kW: Computer Load kW	0.3	--

Efficiency Metric	Value	Units
Average Chiller 1 (40 Ton) Efficiency	0.9	kW/Ton
Average Chiller 2 (100 Ton) Operating Efficiency	1.0	kW/Ton
Chiller 1 Design Efficiency	1.1	kW/Ton
Chiller 2 Design Efficiency	1.3	kW/Ton
AHU 1 Efficiency – Measured	1,367	CFM/kW
AHU 2 Efficiency – Measured	1,375	CFM/kW
AHU 3 Efficiency – Measured	1,387	CFM/kW
AHU 1 Design Efficiency	2,221	CFM/kW
AHU 2 Design Efficiency	2,044	CFM/kW
AHU 3 Design Efficiency	3,219	CFM/kW
Overall HVAC Efficiency	1.3	kW/Ton

The electrical energy characteristics for Data Center 6.2 are shown in the graph below.



In this case, the HVAC loads, at 35%, represented an even larger percentage of the total energy use. Similar opportunities for energy savings exist, and are described in detail in the report. The energy efficiency metrics are listed in the table below. Since Data Center 6.2 utilized fan coil units, rather than computer room air handlers, it was not practical to obtain individual efficiencies.

DATA CENTER 6.2 EFFICIENCY METRICS

Efficiency Metric	Value	Units
UPS1 Efficiency	93%	%
UPS2 Efficiency	90%	%
Cooling kW: Computer Load kW	0.6	--
Chiller 1 Efficiency	1.0	kW/ton
Chiller 2 Efficiency	1.1	kW/ton
Chiller 1,2 Design Efficiency	1.3	kW/ton
Fan Coil Unit Design Efficiency	2370	CFM/kW
Overall HVAC Efficiency	1.6	kW/ton

The chiller efficiency results were comparable to the efficiencies of chillers serving Data Center 6.1. Again, the overall efficiencies are low, as would be expected from air-cooled chillers. Though the efficiencies are comparable to the design efficiencies, better performance is expected, since the operating conditions are more favorable, as discussed earlier. The design efficiencies of the FCUs are comparable to the design efficiencies of the AHUs used in Data Center 6.1, though the actual efficiencies were not measured.

II. Definitions

Data Center Facility	A facility that contains both central communications equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility
Server Farm Facility	A facility that contains both central communications equipment, and data storage and processing equipment associated with a concentration of data cables. Can be used interchangeably with Data Center Facility. Also defined as a common physical space on the Data Center Floor where server equipment is located (i.e. server farm)
Data Center Floor / Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisle ways, caged space, cooling units, electrical panels, fire suppression equipment, and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).[2]
Data Center Occupancy	This is based on a qualitative estimate on how physically loaded the data centers are.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors, and other equipment.
Computer/Server Load Measured Energy Density	Ratio of actual measured Data Center Server Load in Watts (W) to the square foot area (ft^2 or sf) of Data Center Floor. Includes vacant space in floor area

[2] Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft2-gross) or gross watts per square meter (watt/m2-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

Computer Load Density – Rack Footprint	Measured Data Center Server Load in Watts (W) divided by the total area that the racks occupy, or the rack "footprint".
Computer Load Density per Rack	Ratio of actual measured Data Center Server Load in Watts (W) per rack. This is the average density per rack.
Computer /Server Load Projected Energy Density	Ratio of forecasted Data Center Server Load in Watts (W) to square foot area (ft^2 or sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Cooling Load Tons	A unit used to measure the amount of cooling being done. Equivalent to 12,000 British Thermal Units (BTU) per hour.
Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Air Handler Efficiency 1	The air flow (CFM) per power used (kW) by the CRAC unit fan
Air Handler Efficiency 2	The power used (kW), per ton of cooling achieved (ton) by the air-handling unit.
Cooling Load Density	The amount of cooling (tons) in a given area (ft^2 or sf)
Air Flow Density	The air flow (CFM) in a given area (ft^2 or sf)

III. Introduction

This report describes the measurement methodology and results obtained for this case study. The facility contained two Data Centers, which were measured independently. In each data center, electricity end use was determined. This means that the energy consumed by all equipment related to the data center was measured. Such equipment includes the actual computer power consumption, the data center air conditioning equipment, the lighting, and the inefficiencies associated with the uninterruptible power supply (UPS). The computer load density is also determined based on the gross area of the data center. This number, in watts per square foot (W/sf) is the metric typically used by facility engineers to represent the power density. Based on a qualitative observation of the data center occupancy, the computer load density at full occupancy is extrapolated. In addition to the typical W/sf metric, the density is also calculated based on the number of racks, and the rack footprint.

Additional information was collected so that the efficiencies of the cooling equipment could be calculated. These efficiencies are compared to the design efficiencies. Opportunities for energy efficiency improvements are described, which are based on observation of the mechanical system design, and measured performance. General design guidance is presented for consideration in future construction. Data Center specific recommendations are made for the as-built systems.

IV. Site Overview

Facility 6 is located in Silicon Valley in California. Two data centers were monitored for energy consumption at Facility 6. The data centers are in separate office buildings, and constitute a relatively small percentage of the total building area. (less than 10%) The data centers, hereafter referred to as Data Center 6.1, and Data Center 6.2, are 2,400 square feet (sf), and 2,500 sf, respectively. Since the data centers represent a small percentage of the overall building area, whole building power consumption is not relevant to determining the *data center* power consumption, and was not monitored. Both data centers house servers and storage drives, and operate 24 hours a day. One of the data centers serves corporate needs (Data Center 6.1), while the other is mainly used for research and development of new engineering products (Data Center 6.2). Occasionally, during normal business hours, a small number of employees may be in the data centers working with the computers.

Figure – Computer Servers

V. Energy Use – Data Center 6.1

DATA CENTER 6.1: ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The facility utilizes a Balanced Power 225 kVA uninterruptible power supply (UPS) to provide a constant supply of power to the data center at constant delivery voltage (480/277 V). The UPS converts AC current and stores it as DC current in multiple battery packs. When the voltage is needed, it is converted back to AC current. In the event of a power loss, a 400 kW diesel generator will provide power for approximately 10 hours.

Spot power measurements were taken at the UPS, both at the input and output in order to determine computer plug loads, as well as losses at the UPS system.

TABLE 1. UPS ELECTRICAL MEASUREMENTS

	Electrical Use [1]	Units
UPS Input	164.7	kW
UPS Output	154.9	kW
UPS Losses	9.8	kW
UPS Efficiency	94.0	%

1 Average measurement taken on 8/21/02, using the PowerSight Power Meter.

DATA CENTER 6.1: COOLING SYSTEM

The data center is cooled separately from the remainder of the building. A chilled water system cools the data center, as well as several small computer labs. It consists of two Trane air-cooled chillers, a 40 Ton scroll chiller, and a 100 Ton rotary chiller. The nominal efficiencies of the chillers are 1.1 and 1.3 kW/Ton, respectively.[3] The 100-ton chiller is served by the emergency distribution panel (EDP), and is the primary chiller, though the 40 Ton chiller is often run in unison to ensure sufficient supply of chilled water. The chilled water pumps are 1.5 hp (hydraulic horsepower; brake horsepower unlisted) pumps, and are variable speed, controlling based upon a differential pressure set point. A controlled bypass ensures minimum flow through the chillers. The chilled water system branches off into two feeds, one that is dedicated to the data center, and the other that feeds the computer labs.

Power consumption, flow, and chilled water temperatures[4] were measured at each chiller over a period of several days. This was to determine the chiller efficiency over a period of varying temperatures.

The computer room air conditioners are constant-speed air handler units (AHU) that are supplied chilled water. There are three air handlers in total, with total cooling capacities of 286,900 British thermal units per hour (Btu/hr), 551,700 Btu/hr, and 185,400 Btu/hr and design airflows of 9200 cubic feet per minute (cfm), 12,700 cfm, and 8,000 cfm, respectively.[5] Air is returned through grills in the front of the AHU, and exits from the top to ducts that feed the ceiling diffusers. The computer room air handlers control the return air temperature of 70 °F. In addition to the air that is recirculated and cooled by the computer room air handlers, ventilation air is supplied by the main building air conditioning unit. The air handlers do not have humidity control.

Spot measurements of flow, and temperatures were performed at the AHU chilled water supply lines.[6] In addition, flow rate, supply and return chilled water temperatures to all three handlers were monitored over a period of several days.[7] It was necessary to identify the chilled water supplied solely to the data center, in order to segregate the chiller power consumption due to cooling of the data center only. Spot measurements of airflow

[3] Converted from the EER listed on the equipment schedules. The schedule for the 100-ton chiller was incomplete, and therefore, its EER was assumed to be the same as the identical model chillers that are installed for Data Center 6.2. The nominal loads are based on entering evaporator water temperature of 56 °F, leaving evaporator water temperature of 44 °F, entering condenser air temperature of 95 °F, and flow rates of 80 gpm, and 200 gpm.

[4] These were measured using an Elite power measuring instrument, an ultrasonic flow meter for pipe flow, and thermistors inserted in the Pete's plugs at the inlet and outlet of the chilled water line.

[5] The numbering refers to the numbering physically on the units. (CRU #1, CRU #2, CRU #3). This does not correspond with the numbering on the equipment schedule, based on the anticipated motor kW.

[6] These measurements were taken by measuring pressure drop across the circuit setter on the chilled water line, and by measuring temperatures at Pete's Plugs on the supply and return lines.

[7] These measurements were made at the main branch that feeds only these units. Measurements of chilled water temperatures were performed by inserting thermistor probes between insulation and the pipe surface. Flow measurements were made using an ultrasonic flow meter.

through the AHUs were measured along with the AHU power consumption to determine how efficiently air is moved.[8]

The spot measurements, and average of trended measurements are listed in the table below. Please refer to the Appendix for graphs of the measurements over the entire monitored period. The chiller pump and chiller power are proportioned to the data center-cooling load in order to properly determine electrical end use for the data center.

Figure – Data Center Air Handling Unit

[8] Airflow was taken by multiplying the average velocity across the return grille with the grille area, where the velocity was taken with a Shortridge velocity grid.

TABLE 2. COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS

Equipment	Spot / Monitored	Date	Measurement	Units
Chiller Pumps - Total	Spot	8/21/02	4.0	kW
Chiller Pumps - Proportioned based on Data Center Load	Spot	8/21/02	2.0	kW
AHU 1 (Compuaire C)[9]	Spot	8/21/02	3.7	kW
AHU 2 (Compuaire B)[10]	Spot	8/21/02	4.7	kW
AHU 3 (Compuaire A)[11]	Spot	8/21/02	1.8	kW
AHU 1 Tonnage	Spot	8/21/02	12	Tons
AHU 2 Tonnage	Spot	8/21/02	16	Tons
AHU 3 Tonnage	Spot	8/21/02	7	Tons
AHU 1 Airflow	Spot	9/4/02	5,086	CFM
AHU 2 Airflow	Spot	9/4/02	6,494	CFM
AHU 3 Airflow	Spot	9/4/02	2,432	CFM
DC Cooling Load From Chilled Water - Based on AHU Tonnage	Spot	8/21/02	124.0	kW
DC Cooling Load From Chilled Water - From Monitoring of Chilled Water Use	Monitored	8/30/2002 - 9/4/2002	111.0	kW
Chiller 2 Total (100 ton)	Spot	8/21/02	48.0	kW
Chiller 1 (40 ton)	Spot	8/21/02	16.0	kW
DC Chiller kW From Spots 1	Spot	8/21/02	35.4	kW
DC Chiller kW From Monitoring - Average	Monitored	8/30/2002 - 9/4/2002	32.3	kW

1 Individual chiller kW proportioned based on the data center cooling load versus total chiller load. This value will vary even if the data center load stays constant, when the chiller load changes, as the efficiency of the chiller is not constant.

9 Supply Fan Schedule: 9200 cfm, 5 BHP.
10 Supply Fan Schedule: 12700 cfm, 7.5 BHP.
11 Supply Fan Schedule: 8000 cfm, 3 BHP.

DATA CENTER 6.1: LIGHTING

Lighting in the data center consists of T-8 tubular fluorescent lamps, and all lights were on when taking power measurements. Lighting Power: 1.16 kW (Taken on 8/21/02) or 0.5 W/sf.

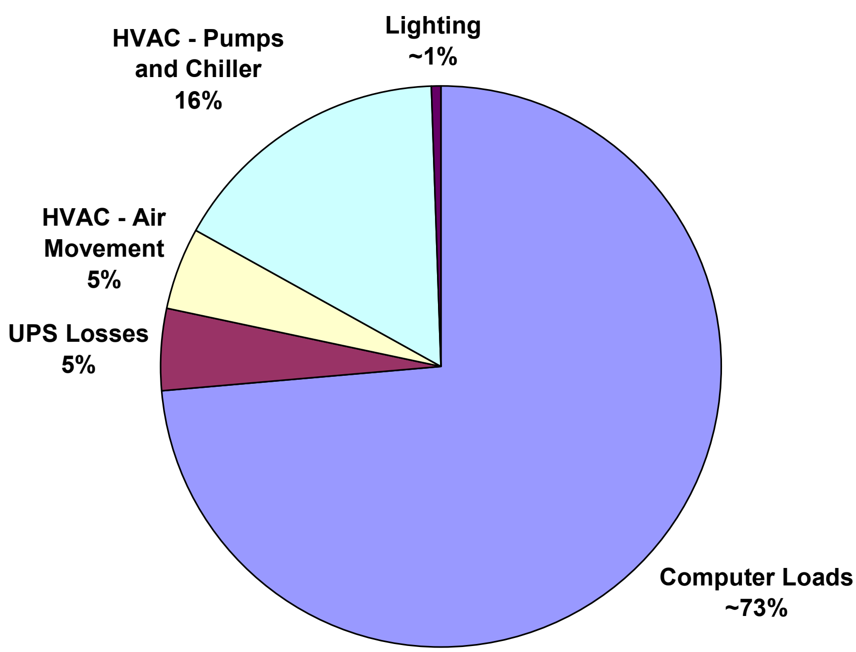
DATA CENTER 6.1: SUMMARY MEASUREMENTS AND METRICS

The table below summarizes the equipment electrical measurements for the data center.

TABLE 3. SUMMARY OF ELECTRICAL MEASUREMENTS

Computer Loads	154.9	kW	73%
UPS Losses	9.8	kW	5%
HVAC - Air Movement	10.0	kW	5%
HVAC - Pumps and Chiller	34.0	kW	16%
Lighting	1.1	kW	1%
Total Energy Use	210.0	kW	100%

These results are shown graphically in the pie chart below.



The computer loads, based on the UPS power supply amounts to 73% of the data center energy usage. Pumping and cooling energy is the second largest consumer at 16%, and air movement specifically is 5%. Together, the HVAC component amounts to 21% of data center energy use, a very significant amount. Therefore, efficiency improvements in energy for HVAC could be significant. Losses in the UPS account for 5% of the data center energy consumption. These losses are more than the lighting, which amounted to only 1% of total energy use.

The electrical and cooling loads can be represented by different metrics. The most commonly used metric among mission critical facilities is the computer load density in watts consumed per square foot. However, the square footage is not always consistent between designers. Some data centers use kVA/rack or kW/rack as a design parameter. Our definition of "Data Center Floor Area" includes the gross area of the data center, which includes rack spaces, aisle spaces, and areas that may eventually contain computer equipment. Per the Uptime Institute, the resulting computer load density in watts per square foot is consistent with what facility engineers use, though this is different from the "footprint" energy density that manufacturers use. We have also calculated the W/sf based on the rack area alone. In addition to the previous metrics, the "non-computer" energy densities are calculated, based on the "data center area". Using the data center occupancy[12] the computer load density at 100% occupancy is projected.

[12] A qualitative assessment of how physically full the data center is. In this facility, occupancy was determined by a visual inspection of how full the racks in place were.

TABLE 4. ELECTRICAL CONSUMPTION METRICS

Data Center Gross Area [1]	2,400	sf
Rack Area	630	sf (Calculated from a total of 121 racks, and area of 1 rack)
"Occupied" %	80%	Estimated from visual inspection.
Based on Gross Area:		
Computer Load Density	65	W/sf
Non-Computer Load Energy Density	23	W/sf
Projected Computer Load Density	81	W/sf
Based on Rack Area: [2]		
Computer Load Density	246	W/sf
Projected Computer Load Density	307	W/sf
On an Individual Rack Basis: [3]		
Computer Load Density	1.3	kW/Rack
Projected Computer Load Density	1.6	kW/Rack

1 Gross area includes spaces between racks; does not include entire building area.

2 This is an important metric, because the data center gross area can vary depending on spacing between racks.

3 This is the average rack computer load.

The computer load density based on the data center area (gross area) is 65 W/sf. At full occupancy, the computer load density is projected to be 81 W/sf. The computer load density based on *rack area* is presently 246 W/sf, and is projected to be 307 W/sf at full occupancy. The average computer load, based on the number of racks is currently 1.3 kW/Rack, projected to be 1.6 kW/Rack at full capacity. The non-computer energy density, which includes HVAC, lighting, and UPS losses, is measured at 23 W/sf.

Since the rack density within data centers and computer types are site specific, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. The "theoretical cooling load" is the same as the sum of the computer loads and lighting loads, together being the plug loads. (There is a small amount of human activity; however, the energy load is insignificant compared to the computer loads.) This is a good cross check of measurements and may also be an indication of the level of cooling that is provided by non data-center dedicated cooling equipment (i.e., general office building, or "house" air to achieve minimum ventilation). The more traditional metrics of energy per ton of cooling (kW/Ton) are calculated for total HVAC efficiency (chillers, pumps, and air handlers), and for the chillers. The air handler efficiency is based on how much air is actually being moved for the measured power consumption.

TABLE 5. HVAC EFFICIENCY METRICS

Metric	Value	Units
Cooling kW: Computer Load kW	0.3	--
Theoretical Cooling Load *	47	Tons
Cooling Provided by AHUs and Chilled Water	32	Tons
Cooling Provided by House Air (Based on Energy Balance)	13	Tons
Combined Chiller Efficiency	1.0	kW/Ton
Average Chiller 1 (40 Ton) Efficiency	0.9	kW/Ton
Chiller 1 Design Efficiency [13]	1.1	kW/Ton
Average Chiller 2 (100 Ton) Operating Efficiency	1.0	kW/Ton
Chiller 2 Design Efficiency [14]	1.3	kW/Ton
Overall HVAC Efficiency	1.3	kW/Ton
AHU 1 Efficiency – Measured	1,367	CFM/kW
AHU 2 Efficiency – Measured	1,375	CFM/kW
AHU 3 Efficiency – Measured	1,387	CFM/kW
AHU 1 Design Efficiency [15]	2,221	CFM/kW
AHU 2 Design Efficiency	2,044	CFM/kW
AHU 3 Design Efficiency	3,219	CFM/kW

* Based on computer loads, lighting loads, and fan energy.

[13] The nominal efficiencies cannot be directly compared to the average operating efficiencies, since the nominal efficiencies are based on full load capacities, and the specific conditions cited previously.
[14] Same as above.
[15] The fan kW is calculated using the schedule fan BhP and an assumed motor efficiency of 90%. Also, please note the numbering has been changed from the equipment schedule to match the numbering on the units.

From the above table it is shown that the "cooling efficiency" is 0.3 kW/kW. This, however, is based on a cooling load that is below the theoretical cooling load by 30%. This suggests that significant cooling is being achieved by the whole building cooling system (package units). The efficiency and operation of this system was not evaluated. However, the whole building system has the ability to provide cooling by supplying outdoor air when the weather is favorable (i.e., economizing), a very efficient way of providing cooling.

The average chiller efficiencies are slightly better than the design efficiencies, which are at ARI conditions. This is expected since the ARI conditions assume 95°F entering condenser air temperature, which is higher than the average temperatures experienced during the monitored period. When outdoor air temperatures are below this temperature, the chiller can reject energy more easily, and therefore has lower power consumption. Based on the outdoor air conditions in this area, better efficiencies are expected. For every 1 °F drop in condenser temperature (outdoor air temperature), the chiller should experience an approximate 2.5% increase in efficiency. In addition, their performance is poor compared to the performance of typical water-cooled chillers. This area is certainly an area of opportunity for energy savings in future construction, and is discussed further in the report. (The Appendix contains additional graphs that show monitored chiller efficiency.)

The air handler airflow delivery efficiencies were measured at 1367, 1375 and 1387 CFM/kW, which are below the design efficiencies by 40-60%. This is likely caused by increased pressure drop in the existing ductwork, which results in a decrease in airflow, compared to the standard testing conditions that are employed when fans are tested. Low pressure-drop duct design is important for achieving high air movement efficiencies.

VI. Energy Use – Data Center 6.2

DATA CENTER 6.2: ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The facility utilizes an International Power Machine 160kVA uninterruptible power supply (UPS1), and a Chloride 50 Power Electronics 50kVA uninterruptible power supply (UPS2) to provide a constant supply of power of constant delivery voltage (480 V) to the data center. The UPS converts AC current and stores it as DC current in multiple battery packs. When the voltage is needed, it is converted back to AC current. In the event of a power loss, a 750 kW diesel generator will provide power for approximately 10 hours. Here as well, spot power measurements were taken at the UPS, both at the input and output in order to determine computer plug loads, as well as losses at the UPS system.

TABLE 6. UPS ELECTRICAL MEASUREMENTS

	Electrical Use [1]	Units
UPS1 Input	103.6	kW
UPS1 Output	96.3	kW
UPS1 Losses	7.3	kW
UPS1 Efficiency	93%	%
UPS2 Input	25.4	kW
UPS2 Output	22.8	kW
UPS2 Losses	2.6	kW
UPS2 Efficiency	90%	%

1 Average measurement taken on 8/27/02, and 8/28/02.

Note, the UPS efficiencies at Data Center 6.2 are slightly higher than the efficiency measured for the UPS serving Data Center 6.1.

DATA CENTER 6.2: COOLING SYSTEM

The data center is cooled by a chilled water system that serves the data center, as well as several small computer labs. The chilled water system consists of two 220 Ton Trane rotary air-cooled chillers. The nominal efficiencies of the chillers are 1.3 kW/Ton.[16] The chillers are piped in parallel, and both are typically operating at all times. The emergency distribution panel (EDP) serves one of the chillers. The chilled water pumps are 8.5 hp (hydraulic horsepower) pumps, and are constant speed. One main pipe feeds the cooling loads on each floor, however, the data center is the last load fed by the main pipe.

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[16] Based on 420 gpm, entering and leaving chilled water temperatures of 56 °F, and 44 °F, respectively, and entering condenser water temperature of 95 °F.

As with data center 6.1 , power consumption, flow, and chilled water temperatures[17] were measured at each chiller over a period of several days. This was to determine the chiller efficiency over a period of varying temperatures.

Unlike the other data center, the chilled water feeds fan coil units (FCUs) in the ceiling plenum, which supplies the overhead duct system. The fan coil units are constant speed and have three –way valves. The system consists of a total of seven fan coil units, with cooling capacities ranging from 104,000 Btu/hr to 190,000 Btu/hr, and design airflow ranging from 5,300 cfm to 9,600 cfm. Air is returned through grills in the ceiling. Minimum outdoor air is brought in through the house air conditioning system. As with Data Center 6.1, there is no humidity control in Data Center 6.2.

The total chilled water load to all the FCUs was monitored using the technique of measuring flow rate, and pipe surface temperatures.[18] As with the previous data center, it was necessary to identify the load solely to the data center, in order to segregate the chiller power consumption due to cooling of the data center only. The number and arrangement of the fan coil units did not allow for measurement of individual fan coil cooling load, nor air supply flow rate.

The spot measurements and average of trended measurements are listed in the table below. Please refer to the Appendix for graphs of the measurements over the entire monitored period. The chiller pump and chiller power are proportioned to the data center cooling load in order to properly determine the electrical end use in the data center.

[17] These were measured using an Elite power-measuring instrument, an ultrasonic flow meter for pipe flow, and thermistors inserted in the Pete's plugs at the inlet and outlet of the chilled water line.

[18] These measurements were made at the main branch that feeds only these units. Measurements of chilled water temperatures were performed by inserting thermistor probes between insulation and the pipe surface. Flow measurements were made using an ultrasonic flow meter.

TABLE 7. COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS

Equipment	Spot / Monitored	Date	Measurement	Units
Chiller Pumps - Total	Spot	9/4/02	23.5	kW
Chiller Pumps - Proportioned by Data Center Load	Spot	9/4/02	4.0	kW
Fan Coils (On circuits 23, 25, 27)	Spot	9/4/02	5.6	kW
Fan Coils (On circuits 29, 31, 33)	Spot	9/4/02	2.5	kW
Fan Coils (On circuits 35, 37, 39)	Spot	9/4/02	11.8	kW
DC Cooling Load From Chilled Water - From Monitoring of Chilled Water Use	Monitored	8/27/02 - 9/4/02	158.0	kW
DC Chiller kW From Monitoring - Average	Monitored	8/27/02 - 9/4/02	45.9	kW

DATA CENTER 6.2: LIGHTING

Lighting in the data center consists of T-8 tubular fluorescent lamps, and all lights were on when taking power measurements. Lighting Power: 2.65 kW (measured on 8/27/02) or 1.1 W/sf. These values are more than double what was measured for Data Center1.

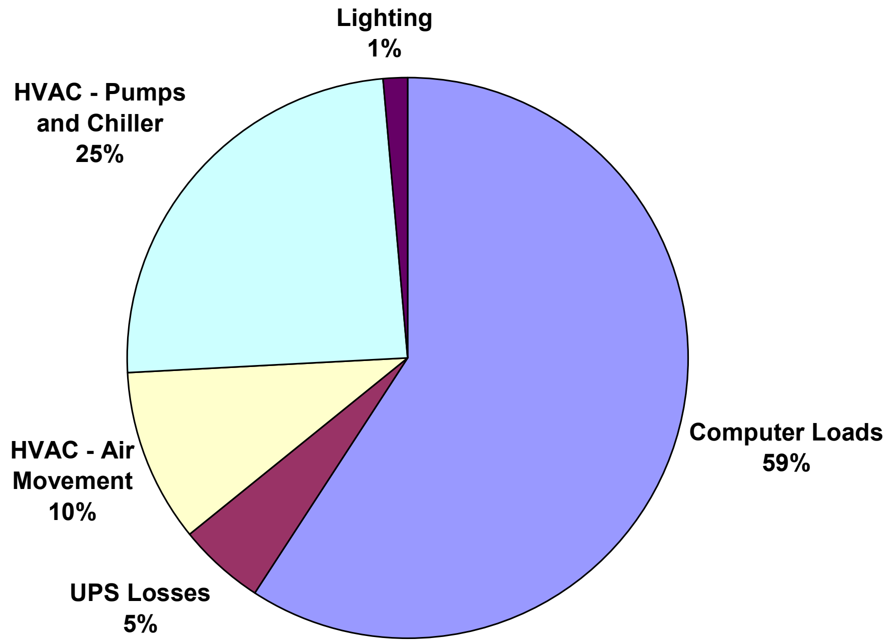
DATA CENTER 6.2: SUMMARY MEASUREMENTS AND METRICS

The table below brings together all the equipment electrical measurements for the data center.

TABLE 8. SUMMARY OF ELECTRICAL MEASUREMENTS

Computer Loads	119.1	KW	59%
UPS Losses	9.9	KW	5%
HVAC - Air Movement	19.9	KW	10%
HVAC - Pumps and Chiller	49.0	KW	25%
Lighting	2.7	KW	1%
Total Energy Use	201.1	KW	100%

These results are shown graphically in the pie chart below.



The computer loads, based on the measured UPS power supply amounts to 59% of the data center energy usage. Pumping and cooling energy is the second largest consumer at 25%, and air movement from the fan coil units is 10%. Together, the HVAC component amounts to a significant 35% of data center energy use. Therefore, the HVAC components provide a significant opportunity for energy savings. Losses at the UPS consume 5% of the data center energy consumption. The percentage of lighting power consumption was the same for this data center, measured at 1%, though the energy density (W/sf) was higher.

Commensurate with the discussion under Data Center 6.1, different metrics are calculated for the data center energy use, and energy efficiency. To briefly reiterate, the computer load density is based on both gross area, which we equate to "data center floor area", and on rack floor area. Both are extrapolated to 100% occupancy to predict future loads.

TABLE 9. ELECTRICAL CONSUMPTION METRICS

Data Center Gross Area	2,500	sf
Rack Area	432	sf (Calculated from a total of 83 racks, and area of 1 rack)
"Occupied" %	50%	Estimated from visual inspection.
Based on Gross Area:		
Computer Load Density	48	W/sf
Non-Computer Load Energy Density	33	W/sf
Projected Computer Load Density	95	W/sf
Based on Rack Area:		
Computer Load Density	276	W/sf
Projected Computer Load Density	551	W/sf
On an Individual Rack Basis:		
Computer Load Density	1.4	kW/Rack
Projected Computer Load Density	2.9	kW/Rack

The computer load density based on the data center area (gross area) is 48 W/sf. At full occupancy, the computer load density is projected to be 95 W/sf. This would require approximately 40 more tons of cooling, which based on the average measured chiller load, could be met by the chillers. The computer load density based on *rack area* is presently 276 W/sf, and is projected to be 551 W/sf at full occupancy. The average computer load, based on the number of racks is currently 1.4 kW/Rack, projected to be 2.9 kW/Rack at full capacity. The non-computer energy density, which includes HVAC, lighting, and UPS losses, is measured at 33 W/sf.

Commensurate with Data Center 6.1, the energy efficiency metrics are shown in the table below.

TABLE 10. HVAC EFFICIENCY METRICS

Metric	Value	Units
Cooling kW: Computer Load kW	0.58	--
Theoretical Cooling Load	40	Tons
Cooling Provided by Chilled Water and Fan Coil Units	44	Tons
Chiller 1 Efficiency	1.0	kW/ton
Chiller 2 Efficiency	1.1	kW/ton
Chiller 1,2 Design Efficiency [19]	1.3	kW/ton
Average Chiller Efficiency	1.0	kW/ton
Fan Coil Unit Design Efficiency	2,370	CFM/kW
Overall HVAC Efficiency	1.6	kW/ton

From the above table it is shown that the "cooling efficiency" of approximately 0.6 kW/kW is significantly less efficient than the cooling efficiency for Data Center 6.1. This can be explained by the differences in equipment, but is not an entirely valid comparison, since Data Center 6.1's metrics suggests that significant cooling was provided by the whole building air conditioning system. This does not appear to be the case with Data Center 6.2, where the measured cooling load was more than 10 tons larger than the theoretical cooling load.[20]

The performance of the chillers is similar to what was observed with Data Center 6.2's chillers. (i.e., The performance was slightly better than ARI rated performance, which is expected for the operating conditions.) However, the performance of water-cooled chillers far outweighs the performance of these units, and is an opportunity for energy savings in future construction.

The design efficiencies of the FCUs are comparable to the design efficiencies of the AHUs used in Data Center 6.1, though the actual efficiencies were not measured.

[19] The nominal efficiencies cannot be directly compared to the average operating efficiencies, since the nominal efficiencies are based on full load capacities, and the specific conditions cited previously.

[20] This can be attributed to measurement error of the cooling load, and that computer loads were assumed to be constant, while they may vary a small percent over time. This assumes, per the drawings, no other fan coil units on the first floor serve non data center rooms, which if present, would explain the small difference.

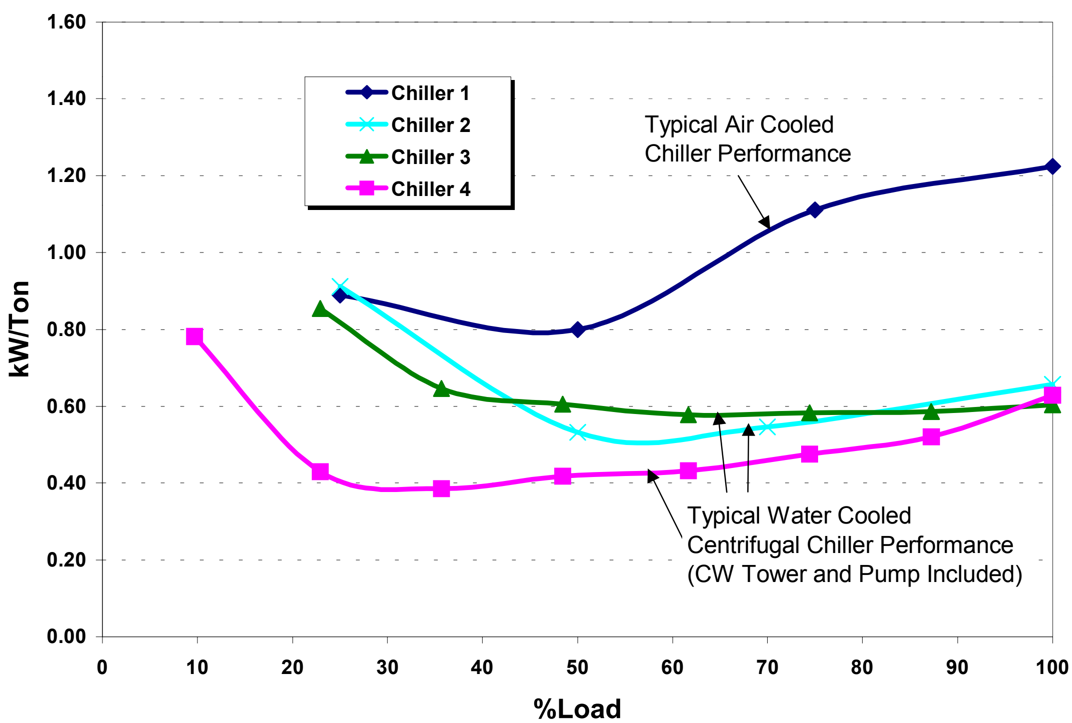
VII. Energy Efficiency Recommendations

General Guidelines for Future Construction

Efficient Chilled Water System

Water-cooled chillers offer enormous energy savings over air-cooled chillers, particularly in dry climates, such as the bay area because they take advantage of evaporative cooling. Since lower temperature media is cooling the chiller, it can reject heat more easily, and does not have to work as hard. Though the addition of a cooling tower adds maintenance costs associated with the water treatment, we have found that the energy savings outweigh the maintenance costs. Within the options of water cooled chillers, variable speed centrifugal are the most energy efficient, because they can operate very efficiently at low loads. The graph below compares the energy performance of various chiller types.

Comparison of Typical Chiller Efficiencies over Load Range

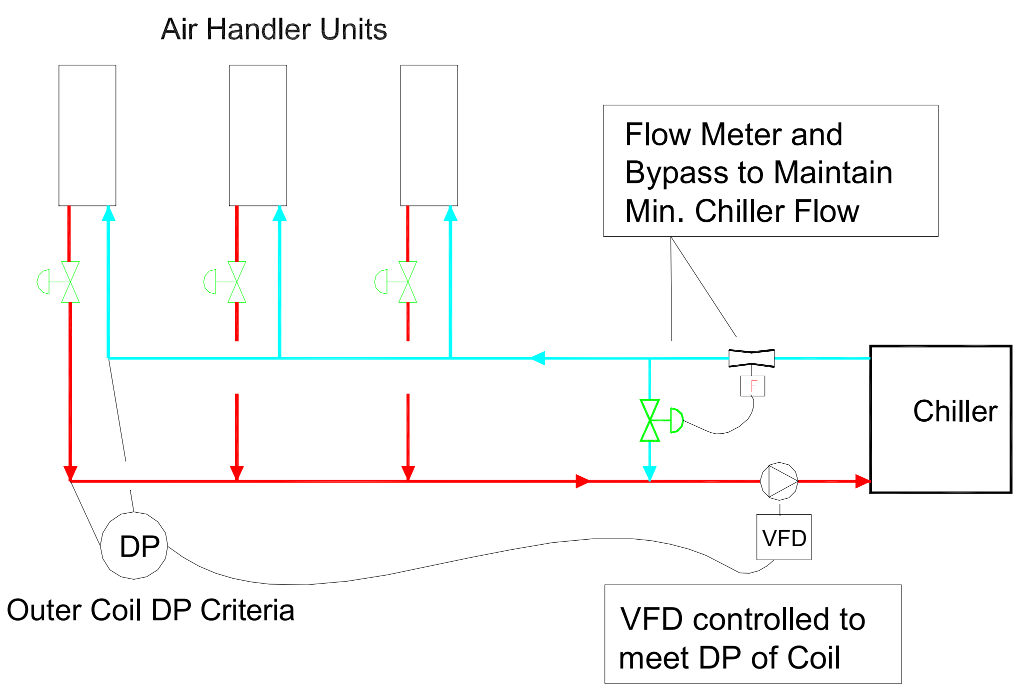


Chiller 1	250-Ton, Screw, Standard Efficiency, Air Cooled
Chiller 2	216-Ton, Screw, Water Cooled
Chiller 3	227-Ton, Centrifugal, Constant Speed, Water Cooled
Chiller 4	227-Ton, Centrifugal, Variable Speed, Water Cooled

Though there are efficient air cooled chillers, the larger size of water cooled chillers has resulted in more care given to efficiency and life cycle costs compared to air cooled chillers.

The selection of the auxiliary equipment, including the cooling tower, pumps, and pumping strategy should also be considered carefully. For example, variable speed fans on cooling towers allow for optimized cooling tower control. Premium efficiency motors and high efficiency pumps are recommended, and variable speed pumping is a ripe opportunity for pump savings. Variable pumping strategies can be achieved in a primary/secondary scheme, where the primary pumps operate at constant speed and directly feed water to the chiller, and the secondary pumps are variable speed and serve the air-handling units. A more energy efficient scheme is primary-only variable speed pumping strategy. Pumping savings are based on the cube law: the cube of the reduction in pump speed reduces pump power, which is directly proportional to the amount of fluid pumped.

A primary only variable pumping strategy must include a bypass valve that ensures minimum flow to the chiller, and the use of two-way valves at the air-handling units in order to achieve lower pumping speeds. The control speed of the bypass valve should also meet the chiller manufacturers recommendations of allowable turndown, such that optimum chiller efficiency is achieved.[21] The diagram below describes the primary-only variable speed pumping strategy.



[21] This basically means that the flow through the chiller should be varied slow enough such that the chiller is able to reach a quasi-steady state condition and able to perform to its maximum efficiency.

Air Management

The standard practice of cooling data centers employs an underfloor system fed by CRAC units. There are a number of potential problems with such systems: an underfloor system works on the basis of thermal stratification. This means that as the cool air is fed from the underfloor, it absorbs energy from the space, warming up as a result, and rises. In order to take advantage of thermal stratification, the return air must be collected at the ceiling level. CRAC units often have low return air grills. Though there are CRAC units available with return grills located on top, the unit may not be tall enough to take advantage of thermal stratification. As a result, the CRAC units are often re-circulating cool or only moderately warmed air. Furthermore, they are often located along the perimeter of the building, and not dispersed throughout the floor area, where they can more effectively treat warm air. One alternative is to install transfer grills from the ceiling to the return grill. Another common problem with underfloor supply is that the underfloor becomes congested with cabling, increasing the resistance to air flow. This results in an increase in fan energy use. A generous underfloor depth is essential for effective air distribution (we have seen 3 feet in one facility).

An alternative to underfloor air distribution is high velocity overhead supply, combined with ceiling height return. A central air handling system can be a very efficient air distribution unit. Design considerations include using VFDs on the fans, low-pressure drop filters, and coils. An additional advantage of a central air handling system is that it can be specified with an economizer function. With the favorable climate in the Bay Area, economizing can reduce the cooling load for a majority of the hours of the year.

Another common problem identified with CRAC units is that they are often fighting each other in order to maintain a constant humidity set point. Not only is a constant humidity set point unnecessary for preventing static electricity (the lower limit is more important), but also it uses extra energy. A central air-handling unit has a better ability to control overall humidity than distributed CRAC units.

Air Management – Rack Configuration

Another factor that influences cooling in data centers is the server rack configuration. It is more logical for the aisles to be arranged such that servers' backs are facing each other, and servers' fronts are facing each other. This way, cool air is draw in through the front, and hot air blown out the back. The Uptime Institute has published documents describing this method for air management.[22] Our observations of both data centers showed an inconsistent rack configuration.

Commissioning of New Systems and Optimized Control Strategies

Many times the predicted energy savings of new and retrofit projects are not fully realized. Often, this is due to poor and/or incomplete implementation of the energy efficiency recommendations. Commissioning is the process of ensuring that the building systems perform as they were intended to by the design. Effective commissioning

[22] http://www.upsite.com/TUIpages/whitepapers/tuiaisles.html

actually begins at the design stage, such that the design strategy is critically reviewed. Either the design engineer can serve as the commissioning agent, or a third party commissioning agent can be hired. Commissioning differentiates from standard start-up testing in that it ensures systems function well relative to each other. In other words, it employs a systems approach.

Many of the problems identified in building systems are often associated with controls. A good controls scheme begins at the design level. In our experience, an effective controls design includes 1) a detailed points list, with accuracy levels, and sensor types, and 2) a detailed sequence of operations. Both of these components are essential for successfully implementing the recommended high efficiency chilled water system described above.

Though commissioning is relatively new to the industry, various organizations have developed standards and guidelines. Such guidelines are available through organizations like the Portland Energy Conservation Inc., at www.peci.org, or ASHRAE, Guideline 1-1996.

Lighting Controls

The lighting power and lighting power densities for Data Center 6.2 were more than twice those of Data Center 6.1. This is likely from occupants/engineers entering the Data Center, and turning the lights on. Lighting controls, such as occupancy sensors may be appropriate for these types of areas that are infrequently, or irregularly occupied. If 24 hour lighting is desired for security reasons, scarce lighting can be provided at all hours, with additional lighting for occupied periods.

Data Center 6.1 Specific Observations

Verification of Bypass Control: The chilled water pumping for Data Center 6.1 utilizes a primary only, variable speed drive (VSD) system, with a bypass control valve. From our observation of the EMCS, the VSD is being controlled via a differential pressure (dP) sensor, however the control scheme for the bypass valve is not clear. A pressure-independent bypass control is the most effective, where the actual flow supplied to the chiller is monitored, and used as the control input to the bypass control valve. A pressure-dependent system will maintain a constant differential pressure, and is controlling flow by using pressure as a surrogate. We suggest that the control scheme for the bypass control valve be examined to ensure that it is being controlled properly.

Three - Way Valves and Bypass: Though primary-only, variable pumping system equipment has been installed, it is not clear whether the air handling units serving the data center and fan coil units serving the computer labs are equipped with two-way valves, as they should be. In order for a variable system to function as intended , the air handling units and fan coil units should be equipped with two way control valves.

Chiller Staging: Constant speed chillers are designed to operate more efficiently at their nominal loads. Currently, both chillers are running most of the time, regardless of the load. (See graphs in Appendix.) It would be more efficient to stage the chillers such that the smaller chiller comes on when the larger chiller is unable to satisfy the cooling requirements. This staging could be based on the primary chiller being unable to meet its chilld water set point. The measured data showed that the load did not exceed 90 tons, and therefore the large chiller should be capable meeting the load most of the time. Attention should be given to how quickly flow is diverted from the primary chiller so that it does not go off inadvertently on low load.

Triple Duty Valves: Triple duty valves have been installed on the discharge of each of the chilled water pumps. We recommend that the triple duty valves be opened completely.

DATA CENTER 6.2 SPECIFIC OBSERVATIONS

Chiller Oscillations: The measured data identified power oscillations with chiller 1. This could be due to cycling of one of the compressors. The controls of this chiller should be investigated, since this cycling effect has an adverse effect on energy consumption and will increase maintenance cost. Though chiller staging is achievable for Data Center 6.1, the measured data shows that the chilled water load for the building hosting Data Center 2 exceeds the nominal load of one chiller.

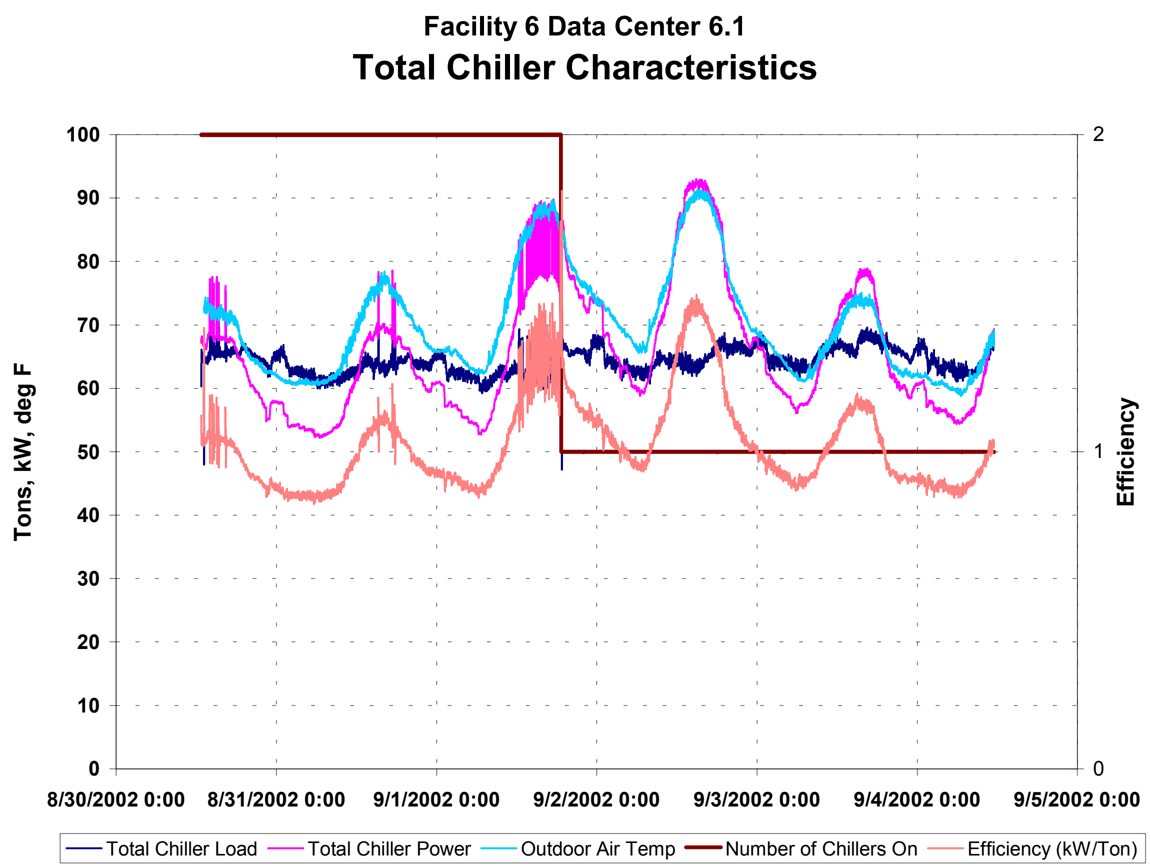
Close 4 Inch Bypass: The mechanical drawings show the existence of a 4-inch bypass on the chilled water loop, located on the first floor. Visual observation of the fan coil units shows the existence of three-way valves (though this differs from the mechanical drawings). Upon confirmation of three-way valves on all fan coil units, this bypass can be closed.

Primary- Only Variable Speed Conversion: The current constant speed pumping strategy could be converted to a variable speed system by installing VSDs on the pumps, installing a controlled bypass line to ensure minimum flow through the chillers, and by converting the three-way valves to two-way valves. Note, this is the system that is already installed on the chilled water system serving Data Center 6.1.

High Velocity Diffusers and Air Management: Both data centers utilize overhead air supply. Diffusers should be sized for high velocities such that air is directed downwards in aisles facing the fronts of the servers. Also see Air Management - Rack Configuration.

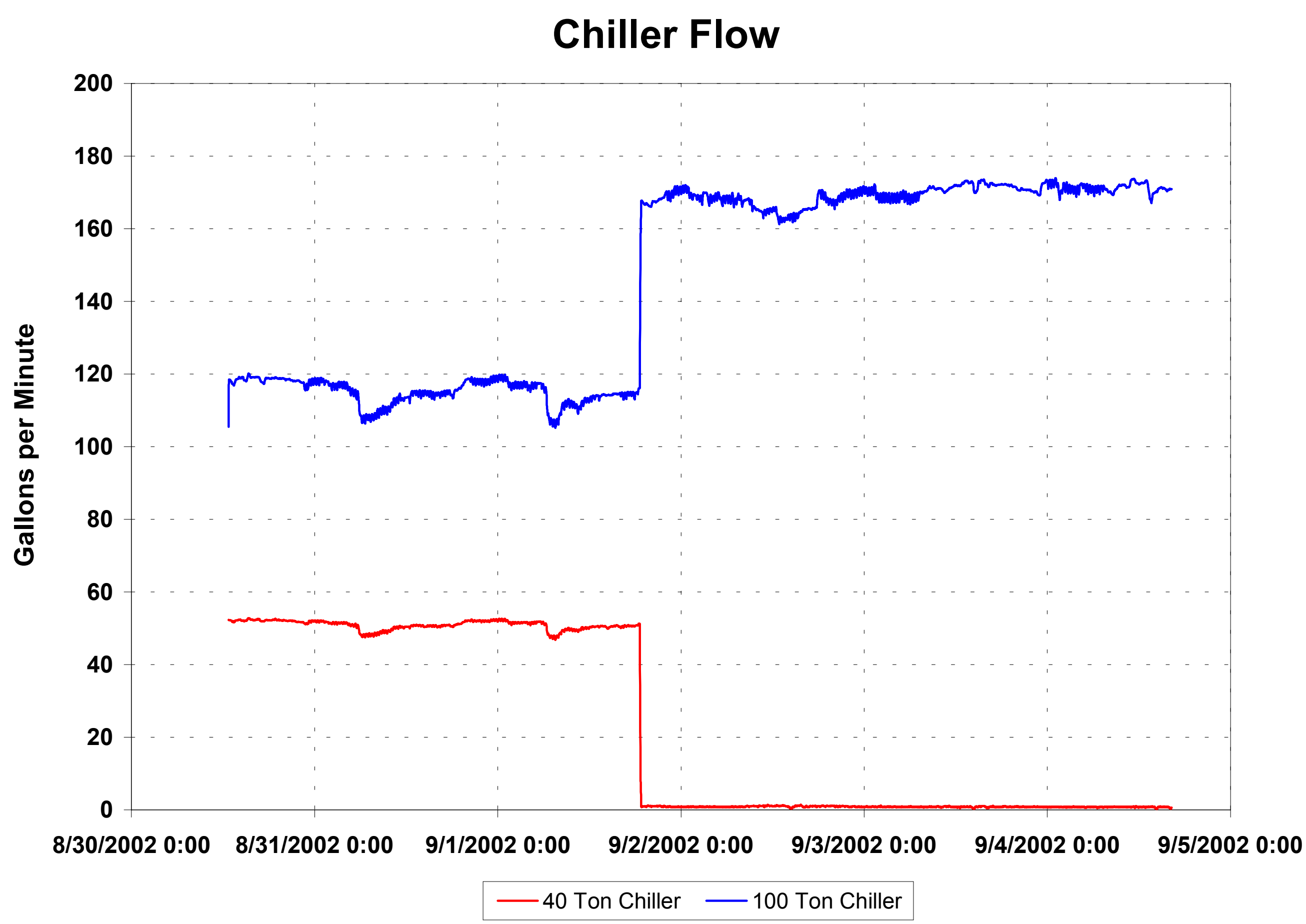
Triple Duty Valves: Triple duty valves have been installed on the discharge of each of the chilled water pumps. We recommend that the triple duty valves be opened, and that the pump impellers be trimmed for balancing. This has the same effect as reducing the pump size and flow, without sacrificing efficiency. If a conversion is made to variable speed pumping, then the impeller does not have to be trimmed.

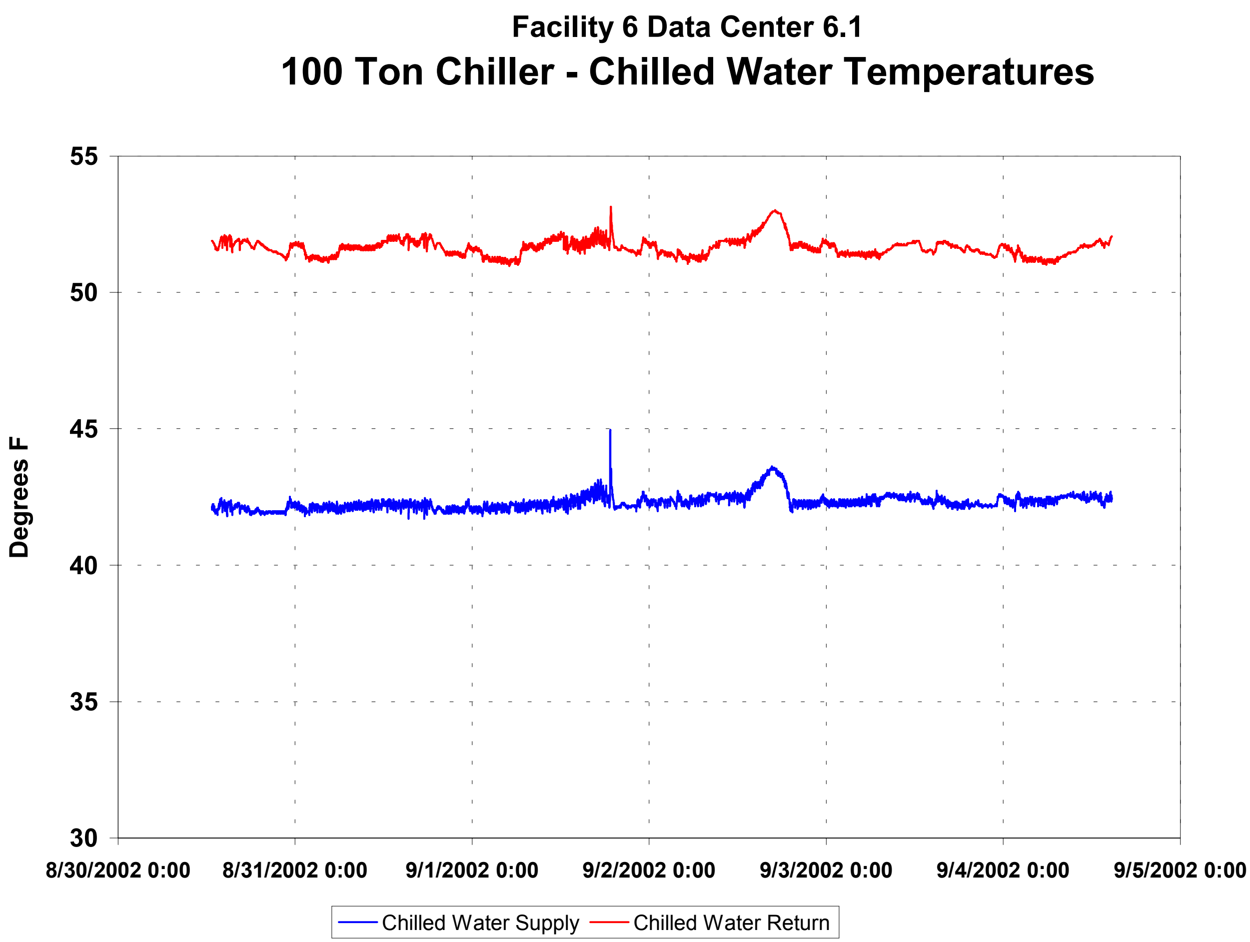
APPENDICES – MONITORED DATA – FACILITY 6, DATA CENTER 6.1



Facility 6 Data Center 6.1
Total Chiller Characteristics
Tons, kW, deg F
Efficiency
100
90
80
70
60
50
40
30
20
10
0
2
1
0
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Total Chiller Load
Total Chiller Power
Outdoor Air Temp
Number of Chillers On
Efficiency (kW/Ton)

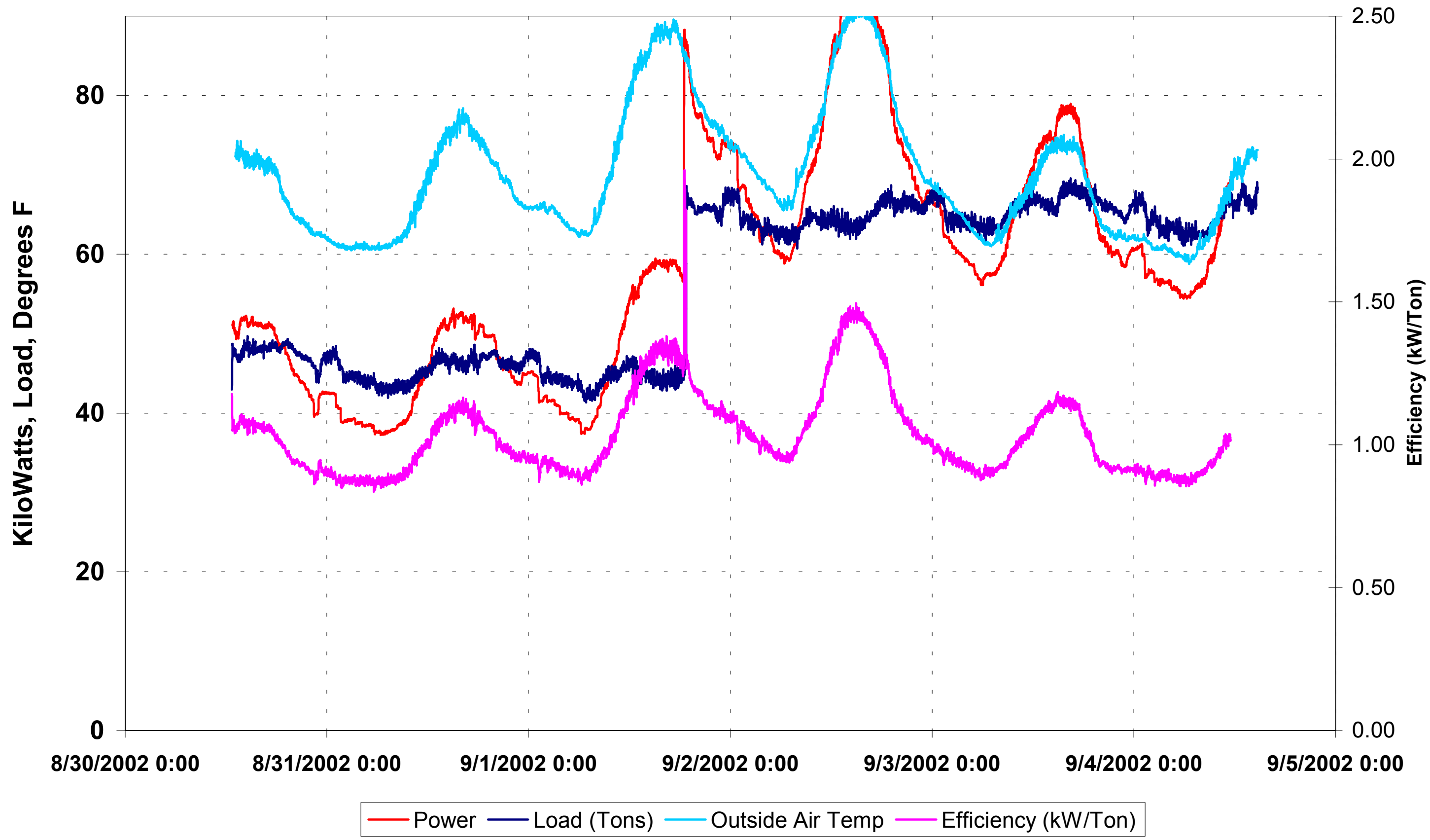
Facility 6 Data Center 6.1

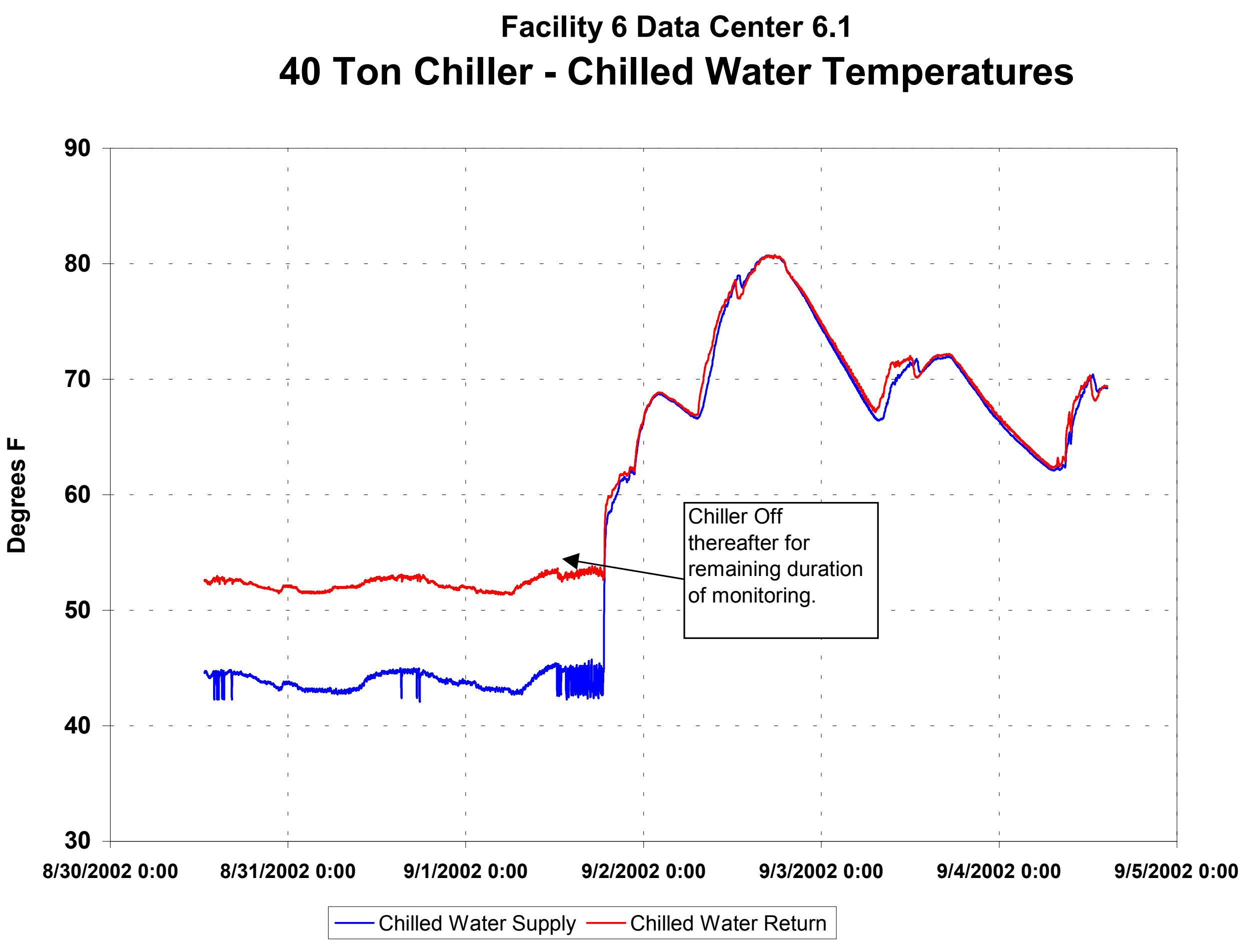


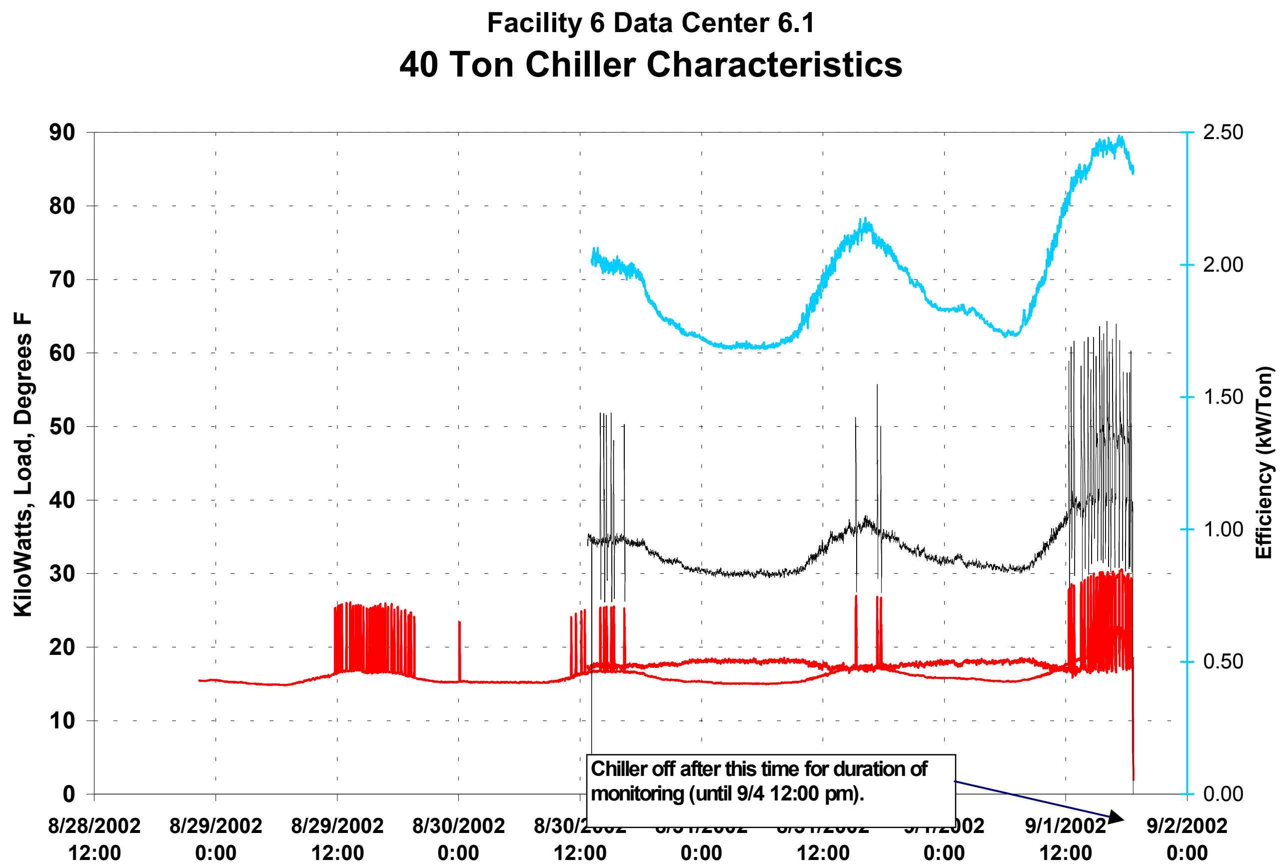

Facility 6 Data Center 6.1
100 Ton Chiller - Chilled Water Temperatures
55
50
45
40
35
30
Degrees F
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Chilled Water Supply
Chilled Water Return

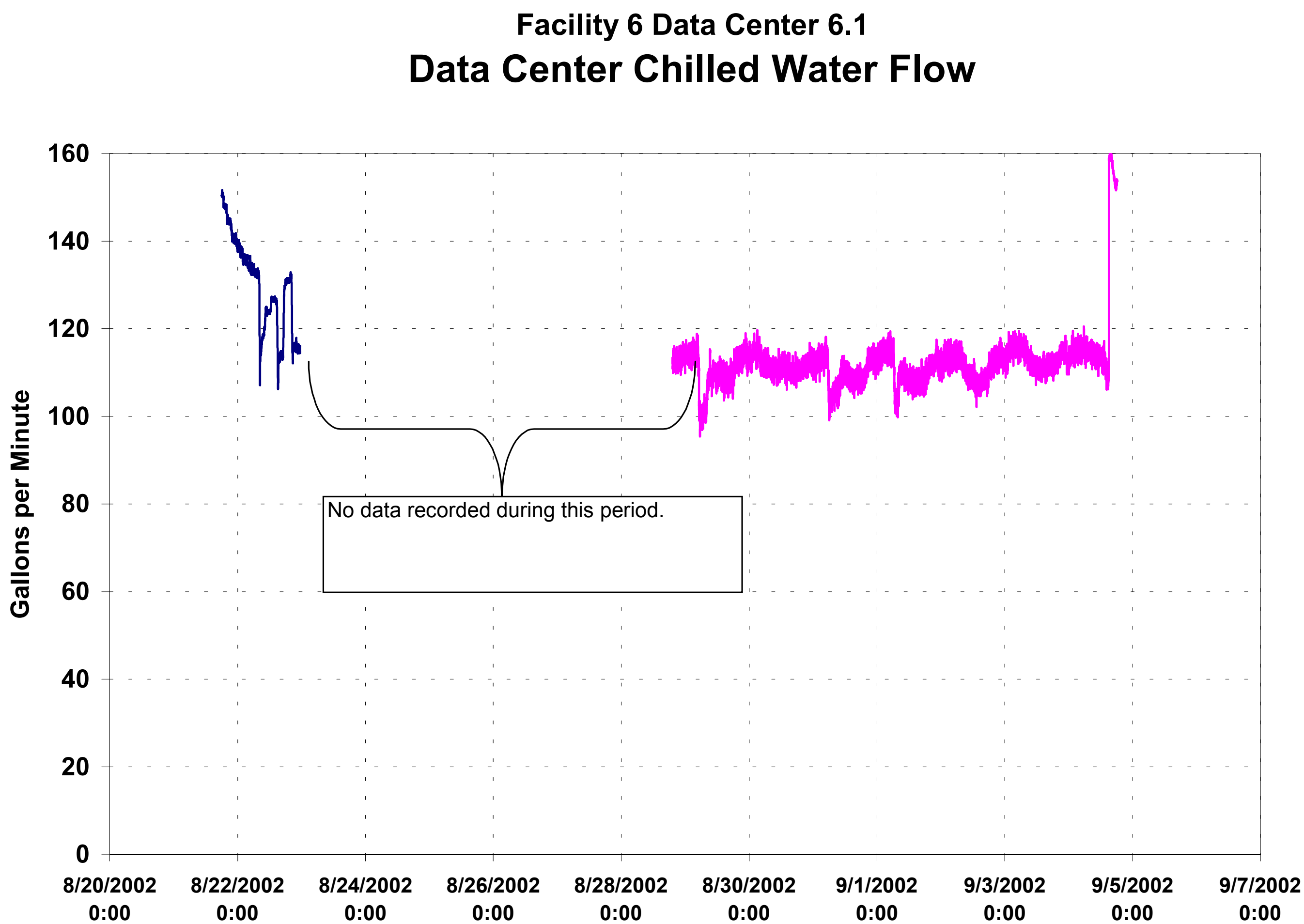
Facility 6 Data Center 6.1

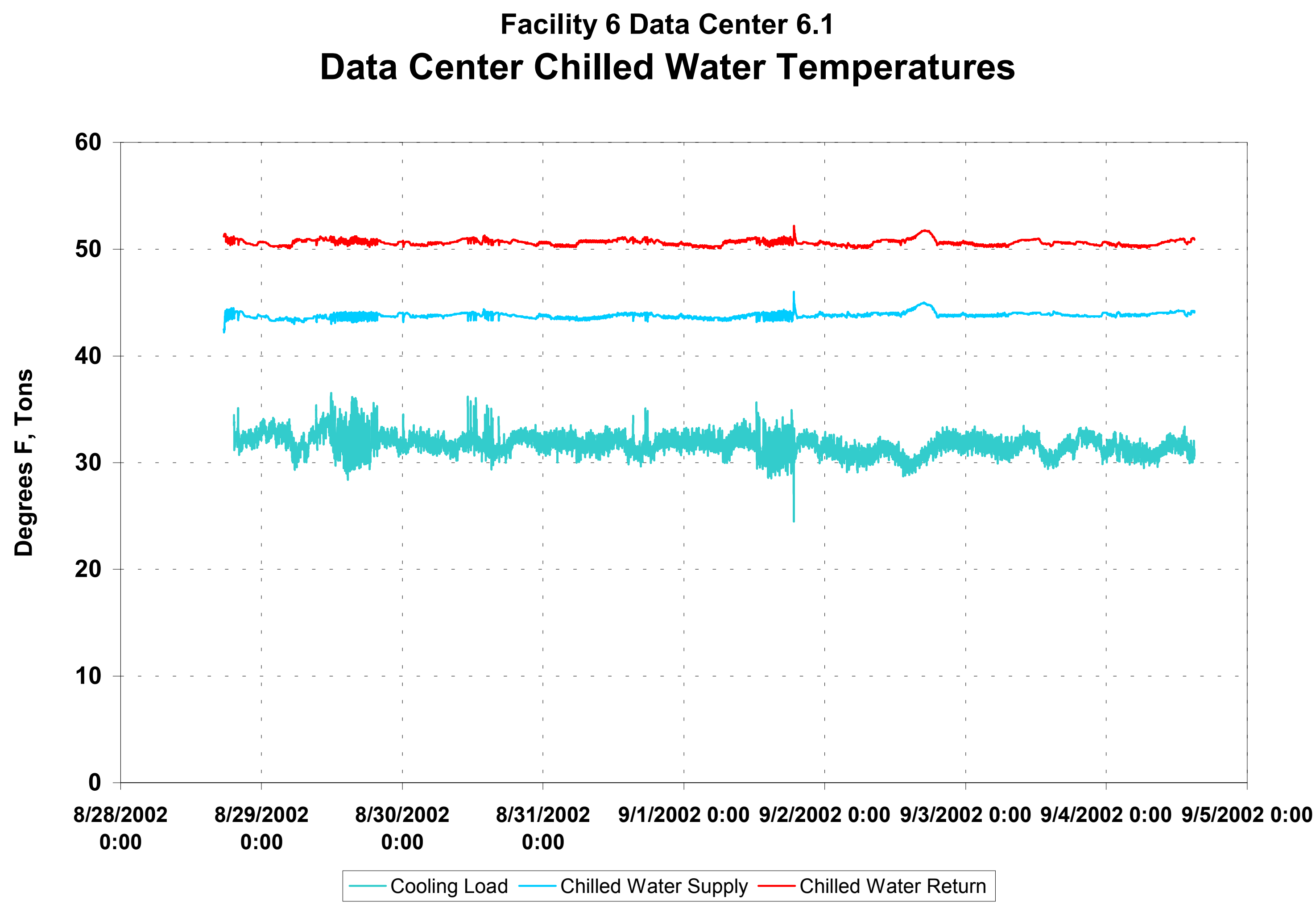
100 Ton Chiller Characteristics

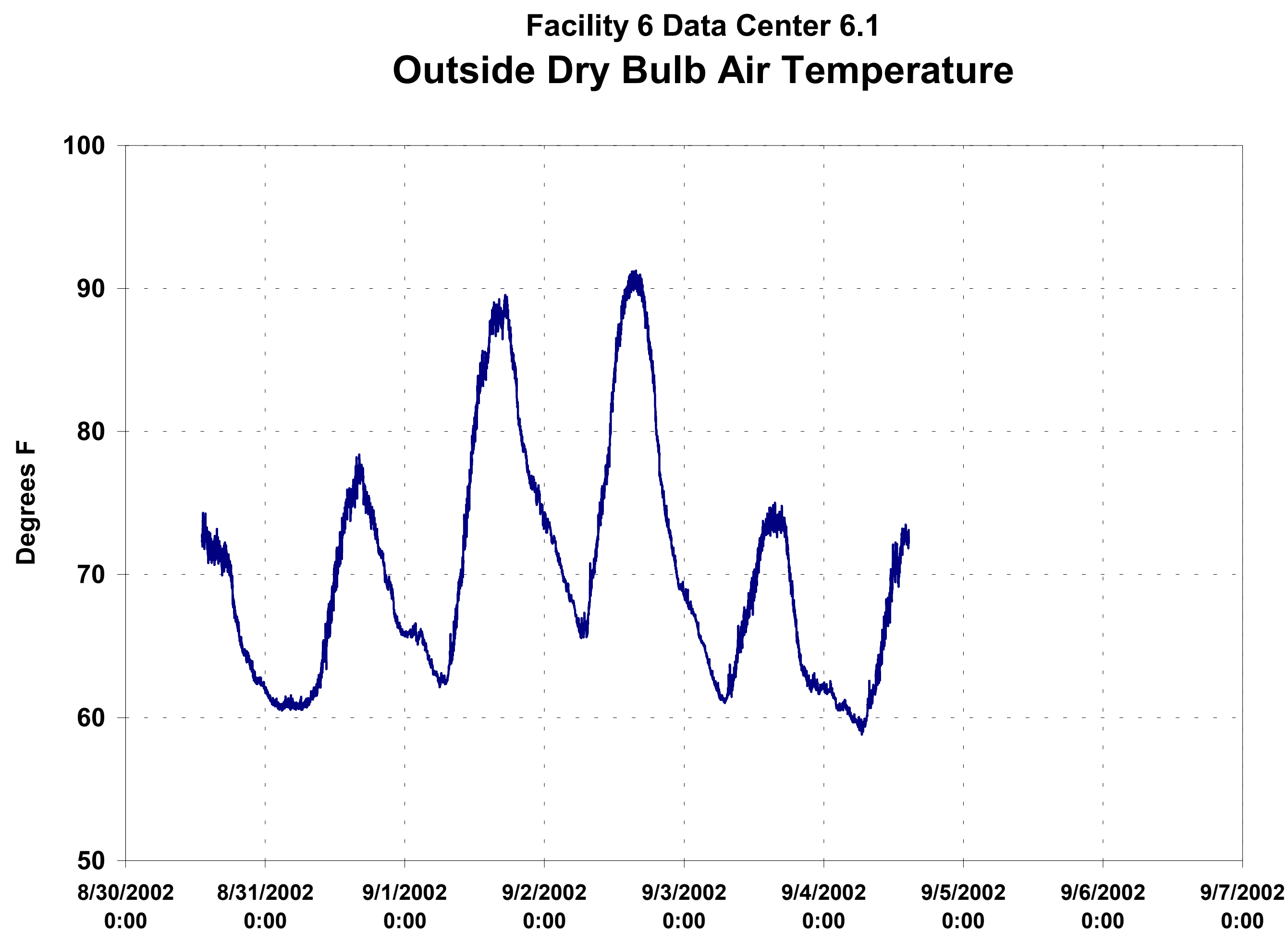



Facility 6 Data Center 6.1
40 Ton Chiller - Chilled Water Temperatures
Degrees F
90
80
70
60
50
40
30
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Chiller Off thereafter for remaining duration of monitoring.
Chilled Water Supply
Chilled Water Return


Facility 6 Data Center 6.1
40 Ton Chiller Characteristics
KiloWatts, Load, Degrees F
Efficiency (kW/Ton)
90
80
70
60
50
40
30
20
10
0
2.50
2.00
1.50
1.00
0.50
0.00
8/28/2002 12:00
8/29/2002 0:00
8/29/2002 12:00
8/30/2002 0:00
9/1/2002 12:00
9/2/2002 0:00
Chiller off after this time for duration of monitoring (until 9/4 12:00 pm).

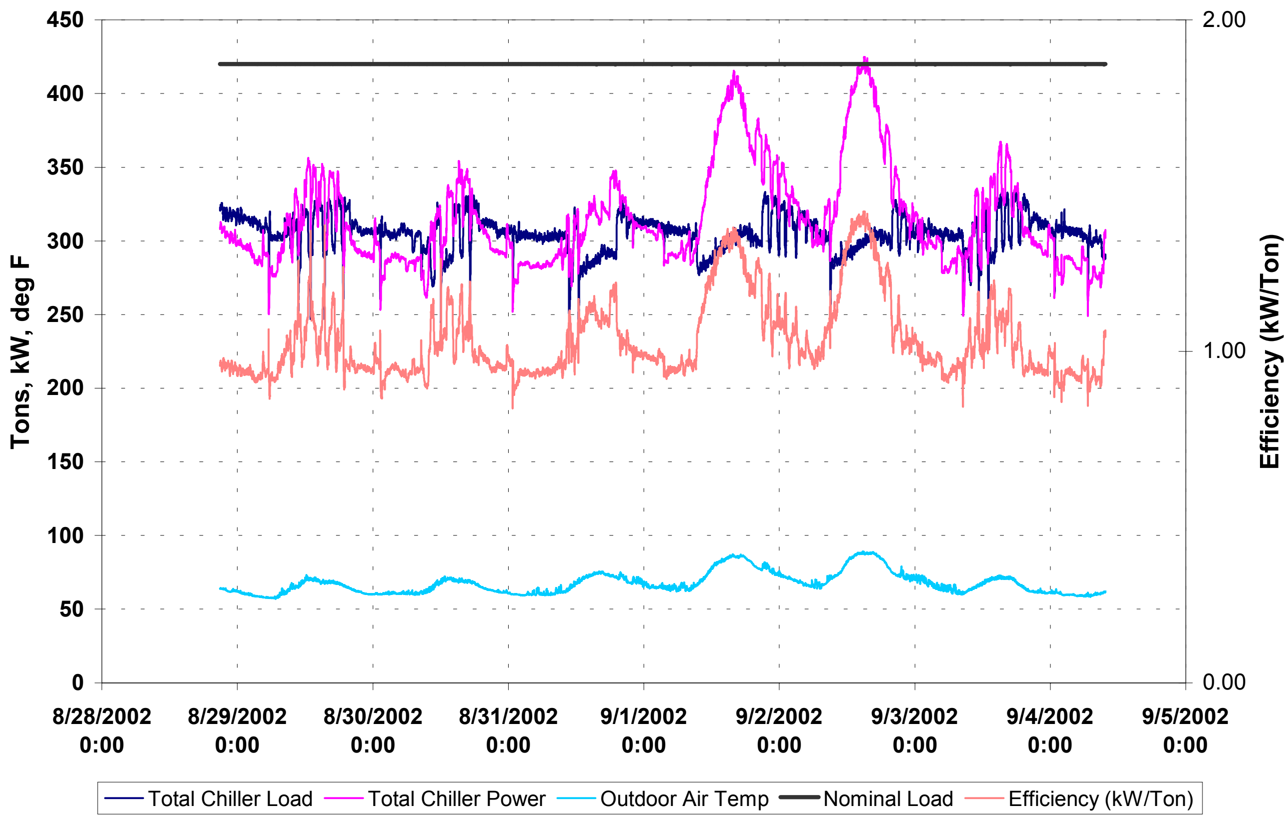

Facility 6 Data Center 6.1
Data Center Chilled Water Flow
Gallons per Minute
160
140
120
100
80
60
40
20
0
8/20/2002 0:00
8/22/2002 0:00
8/24/2002 0:00
8/26/2002 0:00
8/28/2002 0:00
8/30/2002 0:00
9/1/2002 0:00
9/3/2002 0:00
9/5/2002 0:00
9/7/2002 0:00
No data recorded during this period.

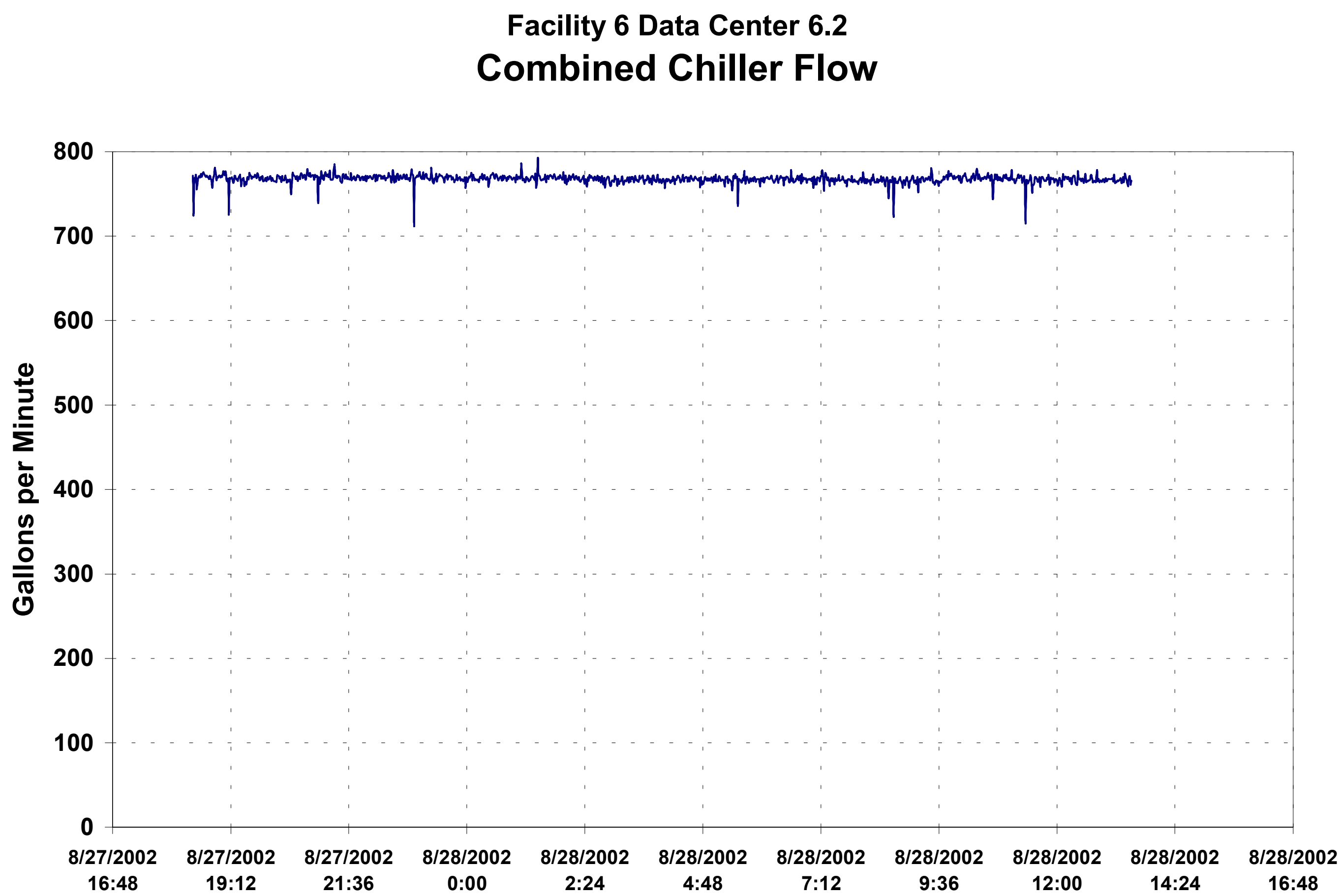

Facility 6 Data Center 6.1
Data Center Chilled Water Temperatures
60
50
40
30
20
10
0
Degrees F, Tons
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Cooling Load
Chilled Water Supply
Chilled Water Return


Facility 6 Data Center 6.1
Outside Dry Bulb Air Temperature
Degrees F
100
90
80
70
60
50
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
9/6/2002 0:00
9/7/2002 0:00

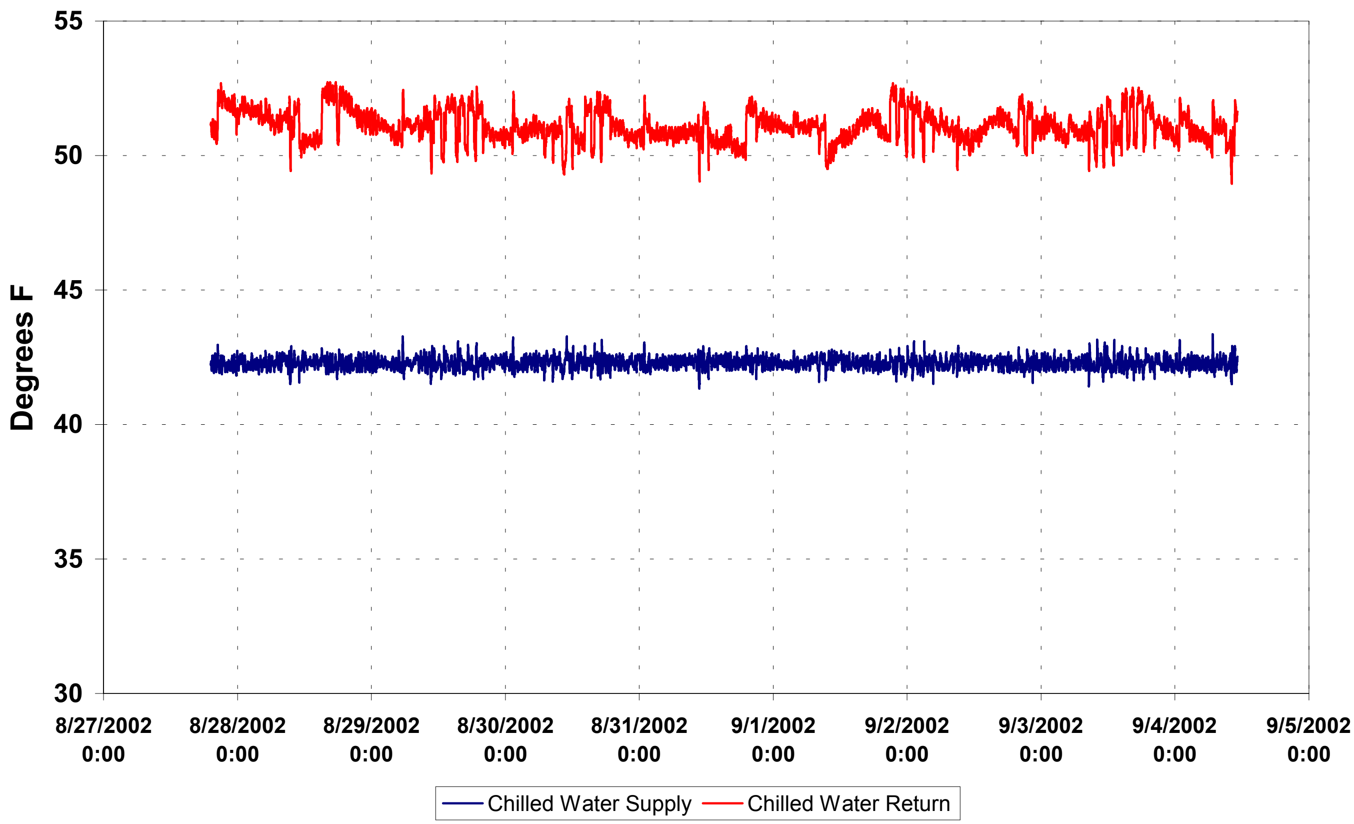
APPENDICES – MONITORED DATA – FACILITY 6, DATA CENTER 6.2

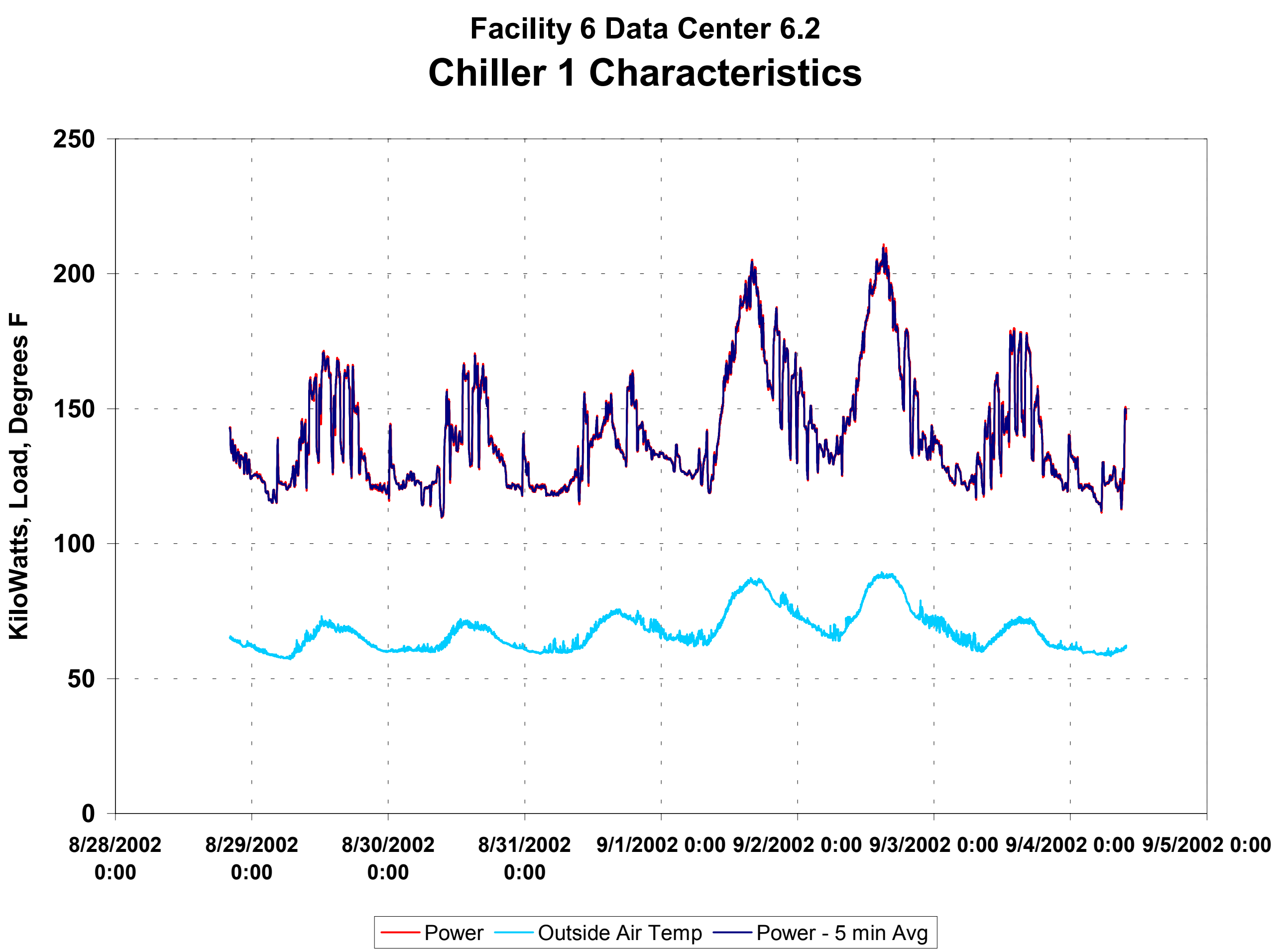
Facility 6 Data Center 6.2
Total Chiller Characteristics

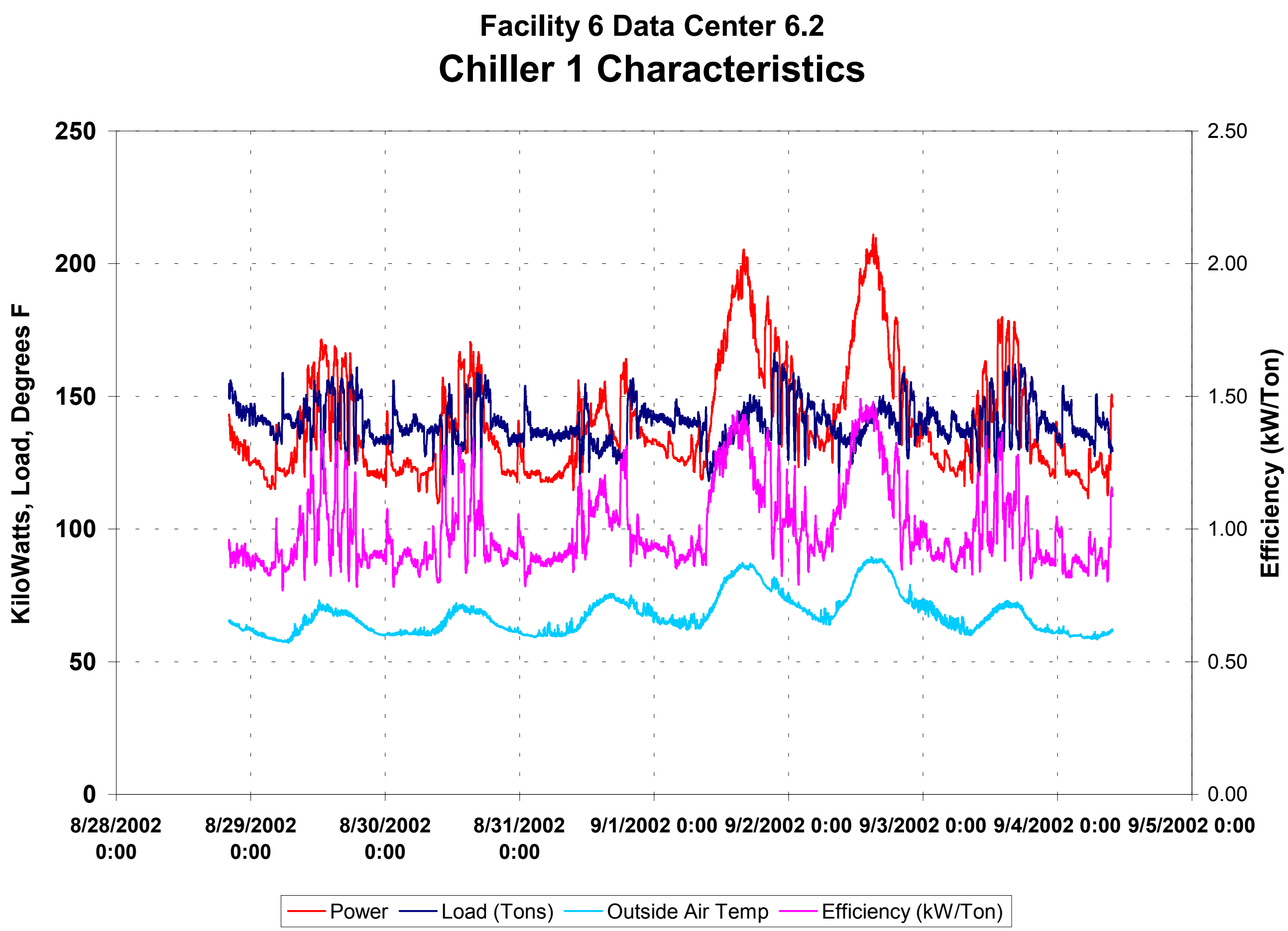


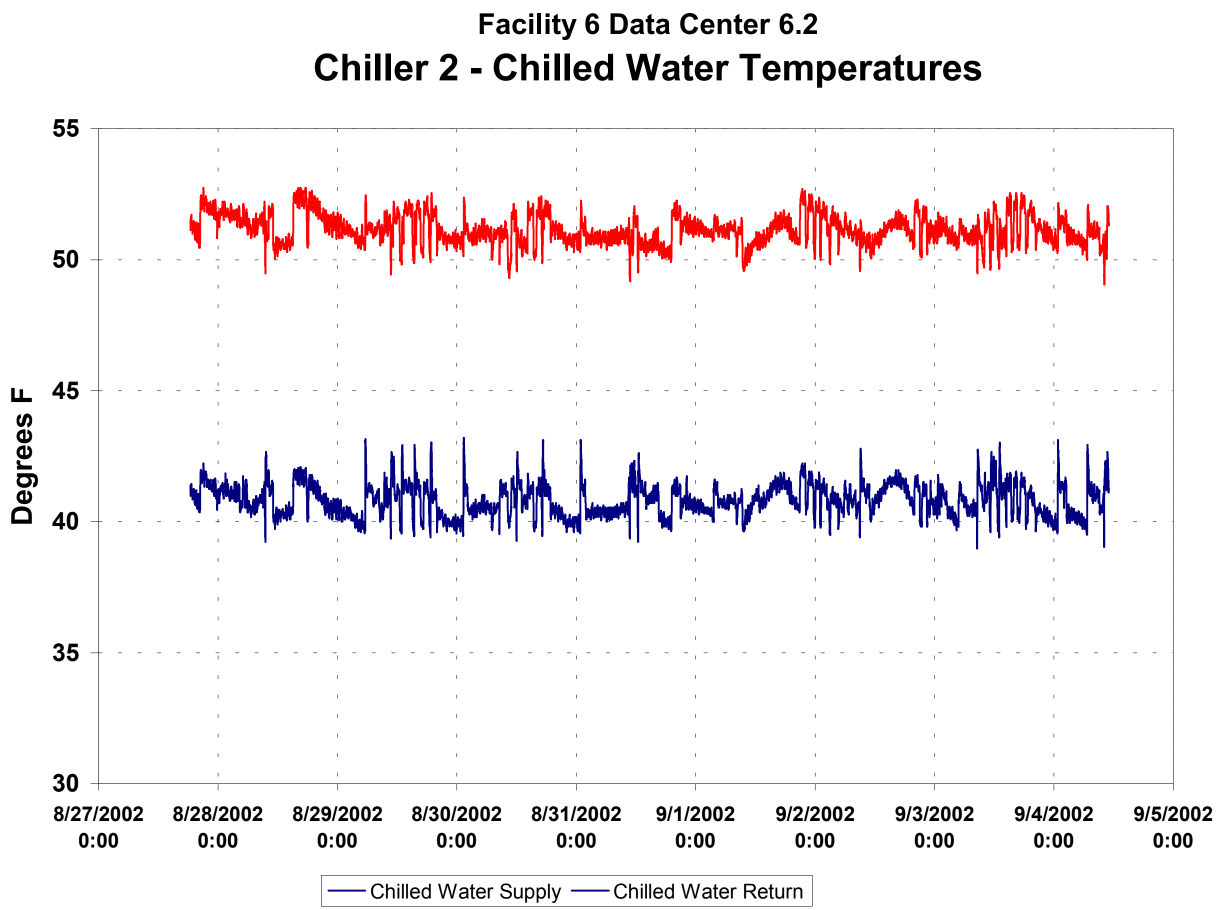

Facility 6 Data Center 6.2
Combined Chiller Flow
Gallons per Minute
800
700
600
500
400
300
200
100
0
8/27/2002 16:48
8/27/2002 19:12
8/27/2002 21:36
8/28/2002 0:00
8/28/2002 2:24
8/28/2002 4:48
8/28/2002 7:12
8/28/2002 9:36
8/28/2002 12:00
8/28/2002 14:24
8/28/2002 16:48

Facility 6 Data Center 6.2
Chiller 1 - Chilled Water Temperatures



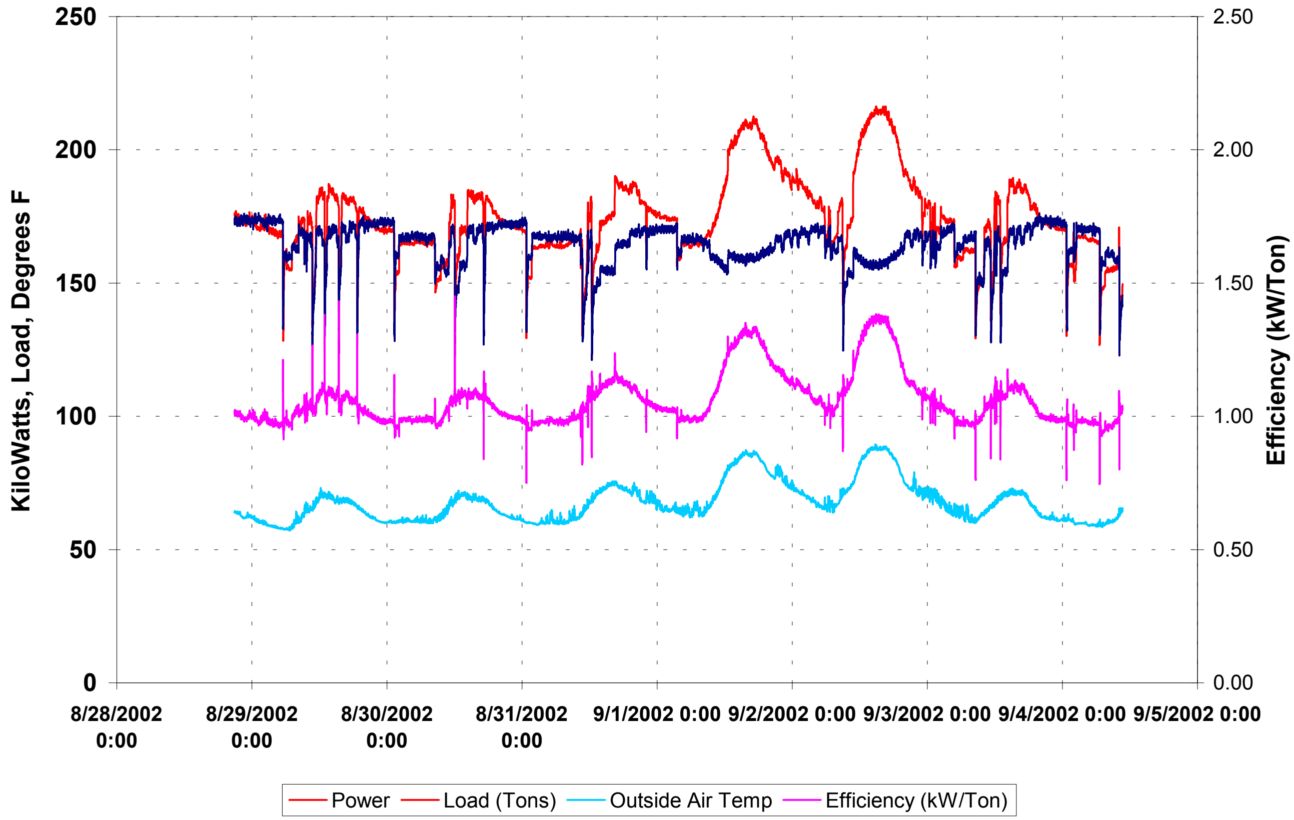

Facility 6 Data Center 6.2
Chiller 1 Characteristics
KiloWatts, Load, Degrees F
250
200
150
100
50
0
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Power
Outside Air Temp
Power - 5 min Avg

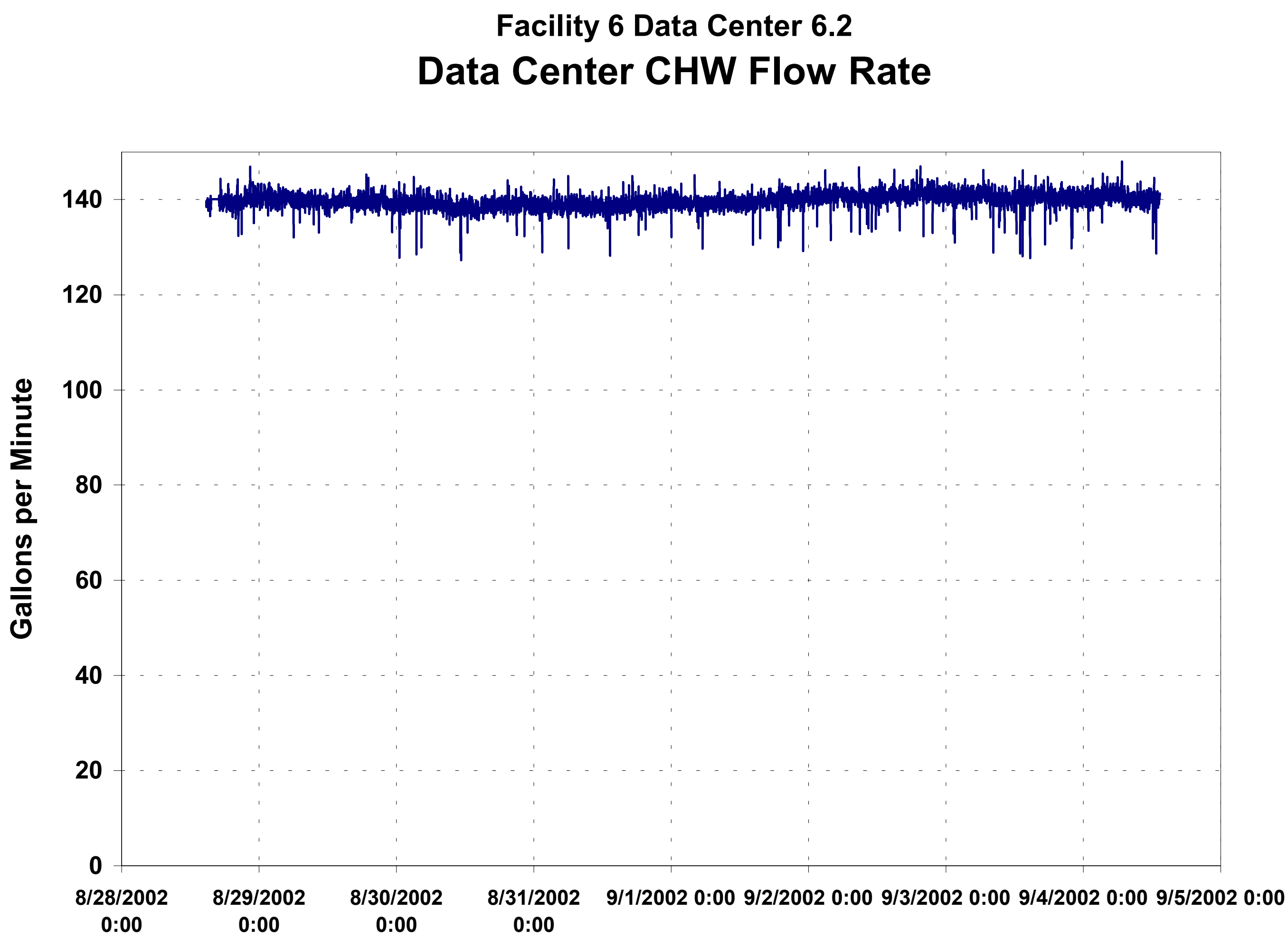

Facility 6 Data Center 6.2
Chiller 1 Characteristics
KiloWatts, Load, Degrees F
Efficiency (kW/Ton)
250
200
150
100
50
0
2.50
2.00
1.50
1.00
0.50
0.00
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Power
Load (Tons)
Outside Air Temp
Efficiency (kW/Ton)



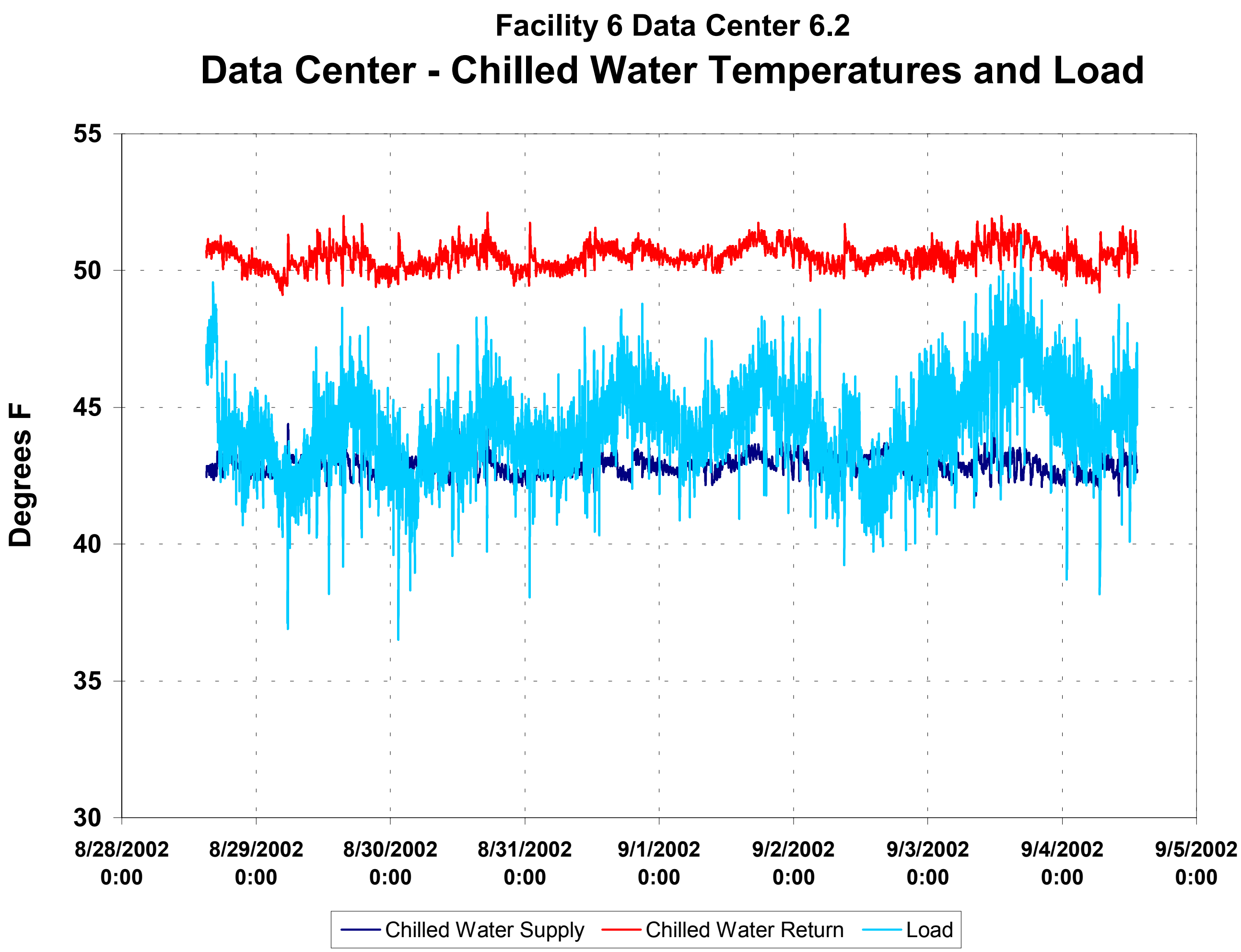
Facility 6 Data Center 6.2
Chiller 2 - Chilled Water Temperatures
55
50
45
40
35
30
Degrees F
8/27/2002 0:00
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Chilled Water Supply
Chilled Water Return

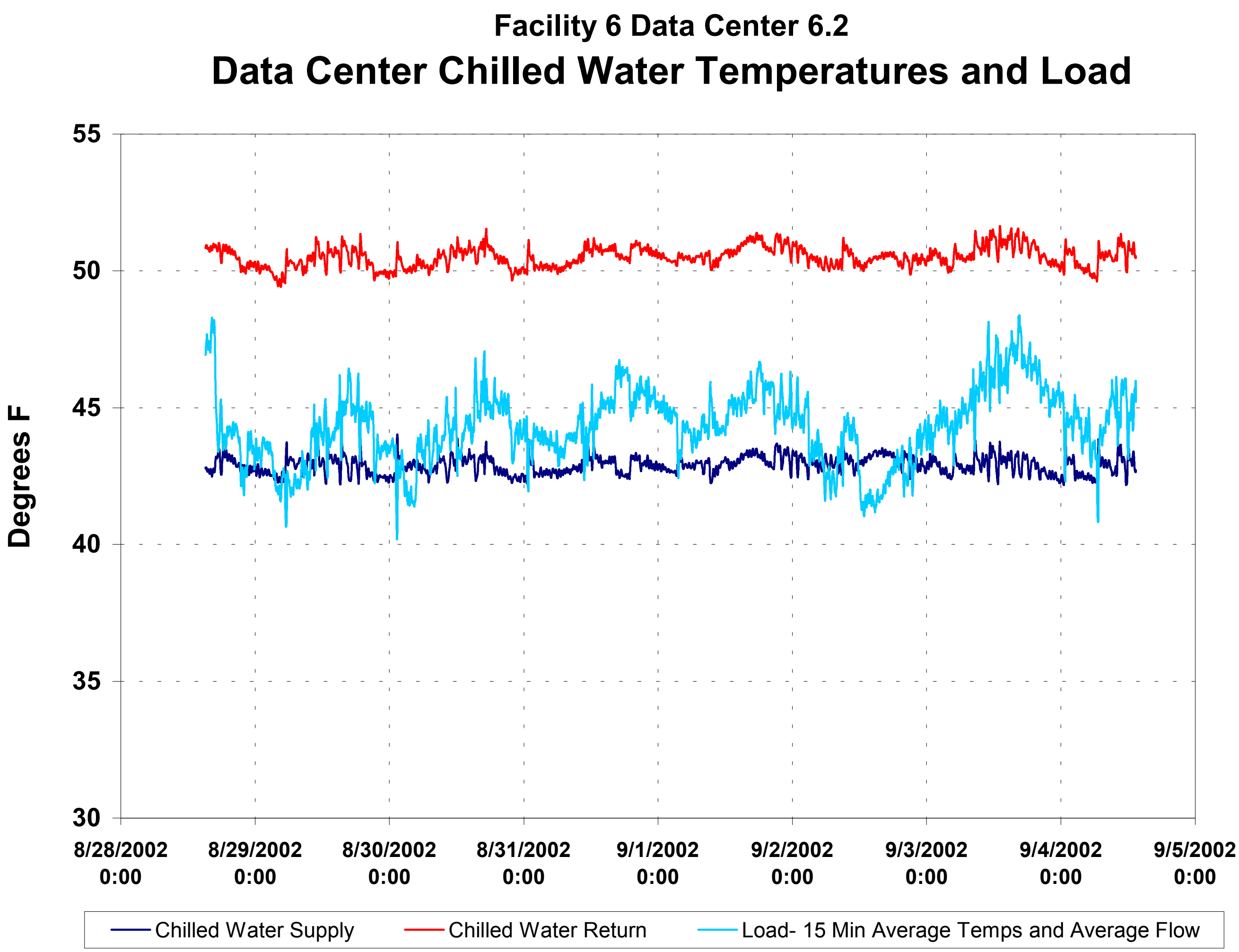
Facility 6 Data Center 6.2
Chiller 2 Characteristics



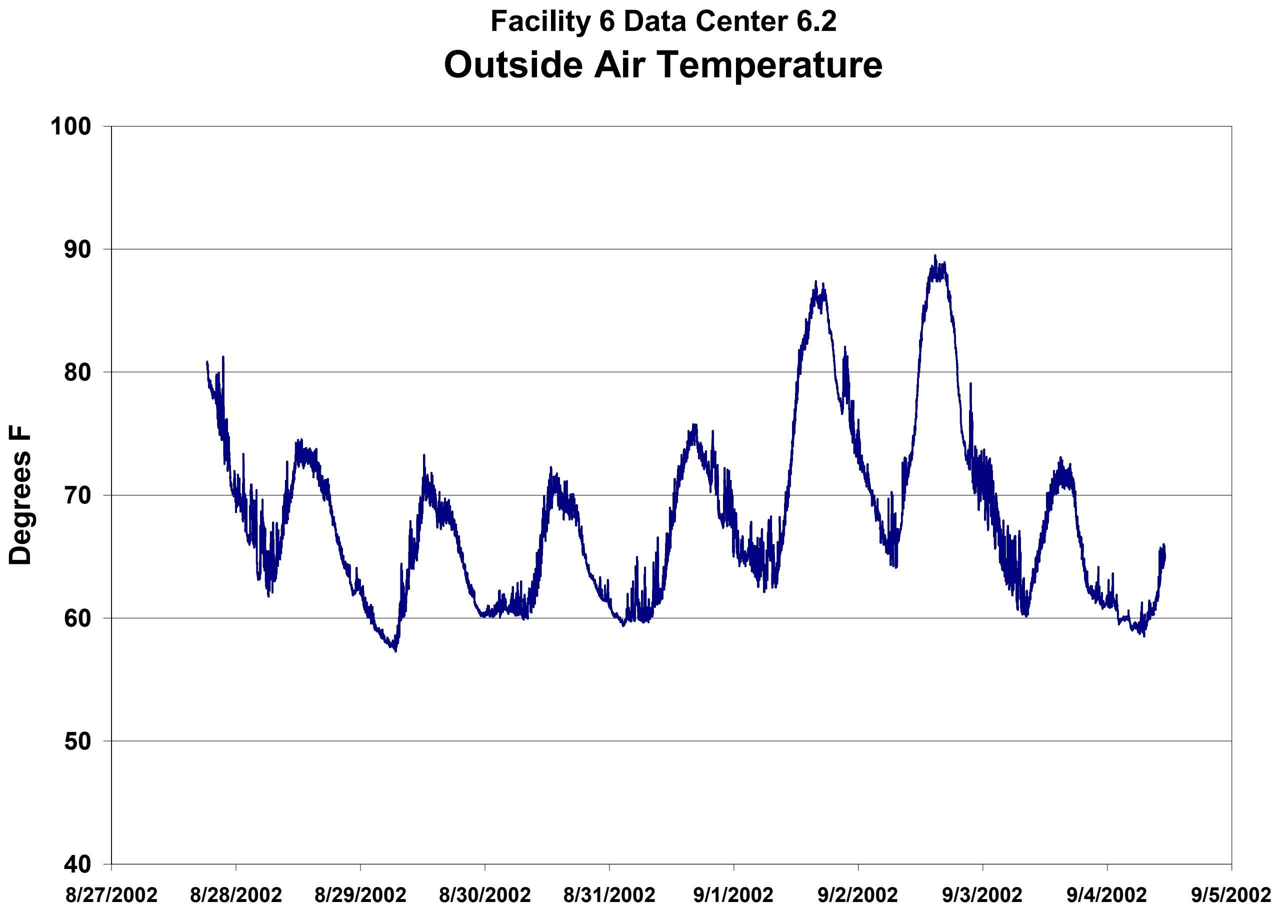


Facility 6 Data Center 6.2
Data Center CHW Flow Rate
Gallons per Minute
0
20
40
60
80
100
120
140
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00


Facility 6 Data Center 6.2
Data Center - Chilled Water Temperatures and Load
Degrees F
55
50
45
40
35
30
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Chilled Water Supply
Chilled Water Return
Load



Facility 6 Data Center 6.2
Data Center Chilled Water Temperatures and Load
Degrees F
55
50
45
40
35
30
8/28/2002 0:00
8/29/2002 0:00
8/30/2002 0:00
8/31/2002 0:00
9/1/2002 0:00
9/2/2002 0:00
9/3/2002 0:00
9/4/2002 0:00
9/5/2002 0:00
Chilled Water Supply
Chilled Water Return
Load- 15 Min Average Temps and Average Flow


Facility 6 Data Center 6.2
Outside Air Temperature
Degrees F
100
90
80
70
60
50
40
8/27/2002
8/28/2002
8/29/2002
8/30/2002
8/31/2002
9/1/2002
9/2/2002
9/3/2002
9/4/2002
9/5/2002